This document is dedicated to

Dr. A P J Abdul Kalam
(Former President of India)
DISCLAIMER

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MESSAGE

Manufacturing is an indispensable enabler for our country's targeted economic growth and in meeting mega societal challenges. In an emerging economy like India, Manufacturing sector has a key role to play owing to its potential to create large scale job opportunities and equitable growth and development.

Currently, our Manufacturing sector is at the crossroads facing difficult times. For the past two decades, this sector had contributed to about 16% of the GDP of our country. This trend needs to be improved. Further, manufacturing should involve technology driven green, lean and clean processes in the coming years.

India is now gearing up for enhancing design capabilities and indigenous product development. The typical pattern of single-product type industry is no longer in vogue. The trend is shifting towards small scale industries and decentralized manufacturing of customized products through adoption of additive manufacturing or 3D printing technology. The recent initiatives taken up by the Government such as Make in India, Start-up India and Digital India collectively focus towards achieving this goal.

I am glad that TIFAC has brought out this Technology Roadmap on Manufacturing at an appropriate time, when our country has laid emphasis on this sector.

I congratulate TIFAC for bringing out this document and I am sure this world be of great value to all the stakeholders.

(Dr. Harsh Vardhan)
MESSAGE

Manufacturing activities act as the multipliers in value-chain, starting from raw material to more expensive intermediates to most sought-after finished products that command a very high value. Brick and mortar manufacturing has the potential to touch upon the fundamentals of any economy. With employment, infrastructure and wealth being created along, manufacturing assures an improved quality of life to a cross-section of people.

With the burgeoning middle-class households and with rising urban population, India is poised to be the fifth largest consumer market in the world. This promises a massive opportunity for Indian manufacturers, not to forget the huge international markets. Progress of any manufacturing sector will be crippled if it does not keep pace with advancements in technology. The sector becomes less competitive and inefficient without timely technological upgrade.

TIFAC has brought out the Manufacturing Technology roadmap at an appropriate time when this sector is giving push for increasing its share in National GDP. I am confident that the insight from the document on current and future global trends will be of immense value to the industry and add to its steam. Also, it can be valuable to the policymakers for creating and enabling ecosystem to crank up manufacturing in the country.

New Delhi
27.06.2016

(Y S CHOWDARY)
MESSAGE

Manufacturing is one of the most important key pre-requisites in realizing the vision captured in the Technology Vision 2035 document, brought out by TIFAC recently. It is a capital and labour intensive activity requiring continuous innovation to have an edge to cater to the ever rising market demands. The Manufacturing sector, as the mainstay of our country’s economy and employment, should therefore strive to confront new challenges continuously in order to endure competition both at the country and global levels.

I appreciate TIFAC for having chosen Manufacturing as one of the key sectors and evolve this roadmap, which entails the broad scenario of different subsectors elaborating the future technology needs, besides highlighting the interventions, both in terms of policy and technology. I am pleased to note that specific recommendations for the stakeholders along with the priorities for research and development have been presented in this document.

I am confident that the key recommendations highlighted in this document will help the stakeholders in formulating and undertaking appropriate actions.

(Ashutosh Sharma)
Manufacturing is a crucial and critical activity for the robust growth of economy, exports and for substantial job creation in any country. While keeping the basic needs like food, water, healthcare, housing and energy as the topmost priority for Indians in 2035, the importance of associated enablers like manufacturing, materials, ICT etc for the economic growth of our country needs to be emphasized. It is often quoted that, manufacturing sector is the force multiplier and any investment in manufacturing yields four times the effect on GDP growth.

Indian manufacturing sector currently contributes around 16% to the GDP, which amounts to a mere 1.8% of the world manufacturing output and is currently at the crossroads braving more competitive manufacturing means and strategies from other nations. Development of Indian manufacturing sector calls for strengthening and reformulating economic reforms that would reinforce the sector and enable it to grow faster and fuel the engine of inclusive growth.

Another worrisome issue is that India’s machine building capabilities need to be augmented manifold to match with our manufacturing targets. Need of the hour is, therefore, to push the manufacturing sector for its sustainable growth particularly ensuring environmental sustainability through green, lean and energy efficient process technologies with optimal utilization of natural resources.

As per the available statistics, it is expected that the next decade would witness substantial demographic change and uneven expansion of working age population. Hence, manufacturing also assumes a key role especially for emerging economies like India, where the sector can potentially generate large scale employment and meaningfully engage sizable populace in economic activities. India needs a rapid growth of the manufacturing sector not only to meet the rising demand but to accommodate millions of new entrants to the workforce.

In view of its utmost importance, TIFAC has considered the manufacturing sector as one of the 12 key sectors, under its Technology Vision 2035 exercise. This exercise is aimed at taking stock of the progress of different sectors, taking into account, new possibilities and challenges in each of them, that our country would see by the year 2035.

The technology roadmap on manufacturing sector analyses the current status and ecosystem in India, global scenario in manufacturing, technology trends and gaps, drivers to change, future technologies, R&D drivers, anticipated challenges and policy imperatives pertaining to eight key segments namely, leather, textile & apparel, chemical, metal fabrication, food processing, electronics & ICT appliances, metal fabrication, composites and micro nano manufacturing.

I am sure that the analysis and recommendations in this document would facilitate the stakeholders - government, industry, R&D and society to take informed decisions about the transformation in manufacturing sector in India in the next few decades.

Dr. Anil Kakodkar
Chairman,
TIFAC
Manufacturing creates both high and low value job opportunities to the growing population, accelerates wealth creation and makes products available to people, to improve the quality of life. Manufacturing is vital to ensure energy and food security apart from being the backbone of infrastructure development, mobility and healthcare. The superior capability of the country in high technology manufacturing is also critical for national security. The slogan, “Make in India” is very apt in this respect and this roadmap is oriented to identifying the technologies and strategies to improve the manufacturing competitiveness of our country.

Manufacturing encompasses a variety of fields ranging from petroleum to food processing and mining to metal fabrication. To be competitive, manufacturing needs continuous innovation and technology development in academic institutions, R&D organisations and industries, and infusion of technology to design offices and shop floors. Manufacturing, therefore, is one of the priority areas in the Technology Vision 2035 exercise.

In this sectoral roadmap document, eight major sectors of manufacturing have been considered under three categories: manufacturing sectors which are already recognised to have potential to make India a global supplier (textile, leather, metal fabrication, chemicals), manufacturing sectors in which India lags behind considerably but is very vital for overall development of manufacturing (electronics and ICT, food processing) and sectors which have recently emerged or emerging wherein India could make a significant impact in the global scene (composites, micro nano manufacturing technology). Some sectors which are not explicitly dealt with in this report could be considered as part of the broad sectors included here.

The Indian manufacturing sector for the past two decades has been contributing to about 16% of the GDP of the nation. It is aspired that by 2035, manufacturing sector ably backed by a vibrant innovation ecosystem and frugal engineering capability, would contribute about 30-35% of GDP and lead to products affordable for people without compromises on safety, efficiency and utility.

The roadmap highlights the need for all the above said sectors to imbibe concepts such as use of smart machines and equipment complete with self-diagnostic capabilities, zero waste and zero defect principles. Adoption of concepts of machine to machine communications, product data influenced by big data and data analytics etc. would bring about a globally connected manufacturing network. Such a process is likely to promote clusters of investment induced, innovation oriented MSME’s who would bring about a good “made in India” brand. The relevance of appropriate levels of skill development, training of trainers and retraining has also been highlighted.

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Prof. P. Radhakrishnan
Chairman, Advisory Committee on Manufacturing Sector,
TIFAC
Bringing out technology vision documents is one of the regular activities of TIFAC. Technology Vision 2020 was the first document of its kind. Keeping in mind the fast changing social, economical and technological scenarios both in India and globe, TIFAC has evolved the Technology Vision 2035 document. This document outlines the aspirations of Indians in 2035, the different prerogatives they would be assured of and also the technologies that would enable them to be achieved.

Manufacturing sector, being the backbone of all industries would be undoubtedly playing a critical role, directly or indirectly in achieving the prerogatives. By 2035, manufacturing would expectedly be a major wealth-producing sector in the Indian economy and would be catering to the needs of at least 150 crore consumers then. In addition, manufacturing would be providing important material support for national infrastructure and strategic sectors as well. Hence, manufacturing sector was identified as one of the 12 key sectors based on which the Technology Vision 2035 document has been scripted. Broadly, bottom-up and top-down approaches were adopted in framing the technology roadmap of this sector.

The technology roadmap exercise on manufacturing kick-started with a brainstorming meet in Delhi in end 2011, in which experts from leading industries, R&D institutions and academia participated and deliberated on selecting sub-sectors of focus, specifically in Manufacturing sector. I convey my heartfelt thanks to all the experts who had participated in the brainstorming meet and set the tone for the exercise.

This technology roadmap exercise was effectively steered by the Advisory Committee, chaired by Prof. P. Radhakrishnan, Director, PSG Institute of Advanced Studies, Coimbatore and Dr. Hant Santhanam, (Formerly) Mahindra & Mahindra was the Co-Chair. Other members of the committee include Dr. Pugazhenthy, E.D, ILZDA, Dr. C. Gajendiran, Former Director, CMTI, Dr. K.V. Raghavan, Former Director - ICT, Dr. T.V. L. Narasimha Rao, GM - Sundaram Clayton, Dr. Gautam Goswami, Scientist-F along with Ms. Jancy A, Scientist-E, TIFAC as Member Secretary. As a result of the various deliberations in the Advisory committee meetings, 8 sub-sectors were shortlisted and authors were identified. Traditional segments such as food processing, textile, leather, chemicals and metal fabrication have been analyzed along side upcoming areas such as composites, micro and nano manufacturing, and electronics and ICT.

Questionnaires focussing on future prospects and technologies in Manufacturing were sent to around 600 professionals across the country and around 100 responses were received. Inputs from them have been collated in the document. TIFAC also had arranged for a platform to document the aspirations of young Indians recently. Aspects of the deliberations specifically related to Manufacturing have also been reflected in various sections of the roadmap.

I express my deepest appreciation and gratitude to all the members of the Advisory Committee for the timeless efforts in bringing this document to its final shape. Special record of appreciation for the unstinting commitment and personal interest shown by Prof. Radhakrishnan during the entire process of framing and scripting this technology roadmap. Thanks for the direction, feedback and assistance provided to us whenever we needed it.
The eight chapters on subsectors have been authored by Prof. P. Radhakrishnan, Dr. K. V. Raghvan, Former Director - IICT, Hyderabad, Dr. T. V. L. Narasimha Rao, GM-Sundaram Clayton, Chennai, Dr. J. Raghava Rao and Dr. J. Sreeram, Senior Scientists from CLRI, Dr. Prakash Vasudevan, Director, SITRA, Dr. Suvendu Bhattacharya, Chief Scientist, CFTRI and Dr. Zacharia Alex, Head, School of Electrical Sciences, VIT. Thanks to all the authors for their technology-enriched inputs and timely cooperation throughout the phase of shaping up this roadmap.

I would like to express my heartfelt thanks to all the members of the National Apex Committee chaired by Dr. Anil Kakodkar, Chairman - TIFAC for the support, valuable insights and guidance in shaping up the Technology Roadmap on Manufacturing -2035.

This document would not have been in this form, without the involvement of our able technical editors, Dr. J. Raghava Rao and Dr. J. Sreeram, Senior Scientists from CLRI. I wish to record my sincere gratitude and thanks for their commitment and pain-staking efforts in finalising the technology roadmap, meticulously in time.

The chapters also have been enriched by value-added inputs from Prof. JP Raina (VIT), Dr. D Chandramouli (CLRI), Mr. S. Sivakumar (SITRA), Dr. Santhanakrishnan & Dr. Kousalya (Avinashilingam University), Dr. Radhahasi (PSG College of Arts and Science), Mr. R. Sakhivel (VIT), Prof. V.K. Jain (IIT Kanpur), Prof. S. S. Joshi (IIT-Bombay), Prof. V. K. Suri (BARC), Dr. Dasaratham Yadav, Prof. V. Radhakrishnan, (IISST), Mr. S. Devarajan, (Formerly) Sundaram Clayton, Prof. Alagirusamy, Textile Department, IIT (D) and Dr. Apurba, Textile Department, IIT (D). Special thanks to all the key contributors for their value addition and guidance.

I convey my heart-felt appreciation to the dedicated scientists, in Technology Vision 2035 team, Dr. Gautam Goswami, Dr. Neeraj Saxena, Ms. Jancy. A, Dr. T. Chakradhar, Ms. Mukti Prasad, Mr. Manishkumar and Ms. Swati Sharma for their technology insights, value-addition and editorial suggestions in bringing out this excellent document.

Special appreciation to the members of Scenario building team, Shri. S. Biswas, Mr. M. Thamarai selvan and Mr. Suresh babu for their involvement. Several aspects of the scenarios which emerged, have been captured in the roadmap.

I am sure, researchers, academicians, funding agencies, policy makers, manufacturers and entrepreneurs with specific interest in the manufacturing sector of India would find this document very interesting.

Prof. Prabhat Ranjan
Executive Director
TIFAC
VISON
2035

Strengthening the manufacturing base of India through innovation-driven clean, green and lean processes.
MANUFACTURING 2035

Green Manufacturing
100% Recycling
Less Water Consumption
Low GHG Emission
Zero Waste
Zero Defect
Lean Manufacturing

CLOUD COMPUTING

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Multiscale Manufacturing
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Product Customisation
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Distributed Manufacturing
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Smart/Intelligent Machines
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Micro Nano Manufacturing
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Reconfigurable Manufacturing
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Modularity/Flexible Manufacturing
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Self Healing/Mending Machines
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Process Intensification

Human Centred Manufacturing
Innovation-receptive Manufacturing

Machine to machine communication

Machine to machine communication

Machine to machine communication

Self Healing/Mending Machines

Self Healing/Mending Machines

Self Healing/Mending Machines
Manufacturing sector is the engine of growth for India. It provides for a stable economy, sells goods to other sectors and in turn buys materials and services from them. An analysis of the contribution of this sector to the GDP of the nation would indicate that it has not contributed to its full potential. The growth of manufacturing sector into an economic powerhouse can only be realized when it imbibes technology and constantly updates the same.

Contributors to the sectoral roadmap begin with analysis of the current Indian and global manufacturing scenario leading to the identification of technology gaps, drivers for change and its possible contribution to the GDP of India. Towards this, eight major manufacturing segments where potential for innovation, creation of jobs and contribution to export earnings exist have been looked into.

Traditional segments such as textile, chemicals, food processing, leather and metal fabrication have been analyzed alongside upcoming areas such as micro and nano manufacturing, electronics and ICT products and composites.

Technology needs to meet increasing export and domestic demands, production of coloured cotton, customized apparels, technical textiles, implementing zero effluent discharge and appropriate adoption of technologies for cost reduction and quality improvement is highlighted in the textile and apparel chapter. Economic utilization of raw material and leather through a technology led growth path and adopting innovation driven manufacturing such that leather remains a consumer preference oriented fashion statement is highlight of the chapter on leather.

The requisite level of technology, infrastructure, skill and needs to reduce emissions from the chemical sector through routes including automation and process intensification has been presented in the chemical manufacturing segment. Chapter on food processing indicates that there is a scope to improve quality attributes of food along with simultaneous reduction of spoilage through innovative technologies, improvisation of supply chain and focus on traditional and health food. Chapter on metal fabrication provides a roadmap on how industry in India can grow in leaps and bounds through adoption of technologies crucial for development of machine tools, fabrication equipment, automation & precision and productive manufacturing. The chapters on micro nano manufacturing, composite fabrication and electronic appliances & ICT products highlight how, inspite of being relatively new domains, they possess the potential to revolutionise the manufacturing sector through development of tools for self assembly, repairs, machining and development of state-of-art fabs for ICT and electronics appliances manufacturing.

Short, medium and long term technology needs for each specific segment has been evolved based on available literature and also based on reports and scenario/trend analysis carried out by specific government departments and those published on the World Wide Web. The document identifies a few grand challenges that manufacturing sector is likely to face by 2035 and also provides a glimpse into possible blue-sky research areas to ensure the sustained global leadership for the sector.

The vision perceived for the manufacturing sector is to create a technology edge that would turn India into a global manufacturing hub, resulting in large-scale job creation and enhanced contribution to GDP. All efforts to provide environmental and economic sustainability for the sector have been envisaged.
The manufacturing sector in India needs to grow through adoption of technology platforms which include nano-engineering, additive and precision manufacturing, adaptive automation, next generation electronics, continuous and sustainable manufacturing. It is perceived that adoption of these would enable the manufacturing sector to meet India’s domestic needs as well as export value added products. Areas requiring development and adoption of technologies for manufacturing of products based on the likely changes in lifestyle and demographic dividend have been identified.

Recommendations that have evolved from this exercise to turn Indian industries as a global hub of manufacturing are a) creating innovation eco-systems at all levels b) developing systems for skill development, upgradation and certification c) emphasis on both economies of scale and scope models based on investment required for technology updation d) making available essential inputs such as raw material and energy at globally competitive rates, e) innovative technologies for frugal utilization of material f) building coalitions and encouraging cluster approach of MSME’s for appropriate investments in R&D, supporting technology acquisition and for design know how.

It is felt that through adoption of the recommendations, the manufacturing sector could ideally contribute 30-35% of GDP by 2035. Accordingly, the technology roadmap concludes by highlighting the need for a concerted effort from stakeholders that includes the government, R&D organizations, industries and academia for realization of the Vision 2035.
Manufacturing sector which encompasses the entire spectrum covering transportation, energy, health, food, housing, clothing, leather, infrastructure, ICT, entertainment and consumer goods is vital and should contribute significantly to GDP of the nation. The competitive industrial performance index places India at a dismal position of 43 amongst 133 countries. Amongst the factors that determine competitiveness, India figures in the top 20 countries only with respect to creating world impact and not so with respect to capacity to produce and export and technology deepening. This has resulted in Indian manufacturing sector contributing only 16% to the GDP as against global best of 30-35%.

The technology roadmap for manufacturing is, therefore, focused on providing employment to the growing population, improving the quality of life, increasing the per capita income to the level of advanced countries, and placing a few Indian manufacturing companies among the top 100 in the world and several hundred Indian products competing globally, successfully in quality, cost and performance with brands from other countries.

By 2035, India should be manufacturing for the world in areas where it has a competitive edge in terms of raw material supply as well as backward and forward integration. This requires both R&D and vastly improved education and massive skill development initiative to increase the productivity of young workforce. There is the need for creating an ecosystem of continuous technology development, upgradation, assimilation and adaptation to make the products competitive.

In order to achieve this vision, it is necessary to scale up through adoption of new manufacturing strategies, creating a broad base of micro, small and medium industries and an effective and efficient ecosystem for transfer of technology from research to business on a scale several fold from the current level of 53 as against global best.

Manufacturing is on the threshold of a massive paradigm change with additive manufacturing, molecular manufacturing, self assembly and several other emerging concepts offering the potential of creating new products through unconventional but more efficient routes in addition to developing vastly improved products through environmentally sustainable and new technologies like micro nano technology.

The vision 2035 for manufacturing requires development of innovative products, development of indigenous manufacturing and next generation ICT for clean, green and lean manufacturing. Changes in education system for enhancing creativity and innovation, developing R&D in emerging technologies and providing adequate infrastructure for seamless manufacturing is required. Educational institutions should bring about mindset changes in cultural disposition to use our own hands.

For the manufacturing sector to reach its envisioned goals of contribution to the nation, it is likely to encounter some challenges requiring technology preparedness, sound implementation strategies and favourable policy environment. Grand challenge that this sector needs to resolve would be guaranteeing sustainability through adoption of appropriate global best practices on material, energy and time management.

Indian manufacturing industry would benefit more from innovative utilization of available indigenous material and their transformation into value added products. Industry may need to adopt principles of additive or cloud manufacturing, cluster approaches to meet common needs etc. This would transform Indian manufacturing into one of micro enterprise model that can produce customized goods based on local needs.
Textile and Apparel industry is the largest in terms of employment potential and has an immense potential for vertically integrated growth. Export as well as domestic demand for quality textile and apparel from India is expected to see marked growth. New technologies like customised apparel production, wearable electronics, technical textiles, zero effluent processes, etc are likely to gain momentum and shall offer a cutting edge advantage to the Indian textile industry.
Textile industry is one of the oldest industries in the world with a rich heritage and is the second largest industry, next only to agriculture in terms of employment potential. The textile and garments sector occupies a significant position in the total volume of merchandise trade across countries. World trade in textiles and clothing amounted to USD 772 billion in 2013.1 Developing countries are the major exporters, which account for a little over two-thirds of the world exports in textiles and clothing. The per capita consumption of textiles throughout the world, including that of the developing countries, has been on the rise over the years and the increased utilization of textile materials in automobile, industrial and other technical areas will only propel it to grow further.

The Indian textile industry can legitimately be proud of its status as being a pioneer in the world owing to its long-standing history and the availability of skilled manpower since time immemorial. It has remained predominantly unorganised until globalisation arrived on the scene. The opening up of the economy gave the much-needed thrust to the Indian textile industry, which now has successfully become one of the largest in the world. Approximately, one out of every six households in the country depends on this sector, either directly or indirectly, for their livelihood, resulting in direct employment to over 45 million people and to another 60 million people who are engaged in its allied activities.2

CURRENT INDIAN AND GLOBAL SCENARIO
Indian scenario: The Indian textile industry contributes about 11 percent to industrial production, 14 percent to the manufacturing sector, 4 percent to the GDP and 10 percent to the country’s total export earnings.3

The fundamental strength of this industry flows from its strong production base of a wide range of fibres/yarns from natural fibres like cotton, jute, silk and wool to synthetic/man-made fibres like polyester, viscose, nylon and acrylic. Per capita consumption of fibre in 2011 for the world taken as a whole was pegged at 11 kg of which cotton was about 3.5 kg, representing...
32% of the total consumption. India’s per capita consumption is about 2/3rd of the world’s per capita consumption. However, this trend is likely to change in the future years due to the growing economy and the resulting purchasing power in India. The fashion trend in India is moving from “need based clothing” to “occasion specific dressing” and is projected to move further to “fashion & detail oriented” dressing.

From environmental point of view, textile industry is recognized as a major polluter. It discharges great amount of water contaminated with dyes, finishing chemicals, cleaning compounds, wax and lanolin removed from natural fibres, and compounds used to produce synthetic fibres into rivers, streams, and lakes. Gaseous emission includes excess heat, fly ash, carbon dioxide, formaldehyde, sulfurous and nitrous compounds that contribute to acid rain. Excess packaging, discarded cardboard and paper goods, empty metal drums, hazardous and toxic chemicals are deposited in landfills. Other environmental problems are high intensity noise in spinning and weaving rooms and dust and airborne debris in opening and spinning areas. Developing eco-friendly processes in textile Industry is one of the major challenges in the present scenario.

Global scenario: The USA, European Union and Canada are the major importers in the global textile market while Asian countries have been the major sourcing region for imports of textiles and clothing by both USA and European Union. The next important sourcing region for USA has been the Latin American countries while the same for European Union have been Central and East European countries. For Canada, the principal sourcing region has been the USA, while Asia finishes at a close second; this obviously points to the fact that there has been a great deal of re-exports from USA. As far as the position of individual countries in all these markets are concerned, the nations like China, Mexico, Turkey and India occupy dominant positions. India is one of the leading suppliers of readymade garments to USA. In the EU market also, India is a preferred supplier for many of the textile products. It is forecasted that, in a few years from now, Turkey would emerge as the biggest competitor for both India and China. Countries like Mexico, Caribbean Basin Initiative (CBI) countries, many of the African countries and Bangladesh have also emerged as exporters of readymade garments not because they have an established textile base, but, on the strength of preferential tariff arrangement under the quota regime.

In so far as the resource-based advantage is concerned, it may be said that countries like India, Pakistan, China, Uzbekistan, Turkey and USA have the same in cotton; China, India, Vietnam and Brazil in silk; Australia, China, New Zealand and India in wool and China, India, Indonesia, Taiwan, Turkey, USA, Korea and a few CIS countries in man-made fibres. In addition, China, India, Pakistan, USA and Indonesia have capacity based advantages in the textile spinning and weaving. In spite of all these, India hasn’t been able to make optimal capacity utilization due to lack of quality awareness and lack of professional management as, majority of home grown textile units are family-owned enterprises.

India’s share in global textiles has increased by 17.5% in the year 2013 compared to the previous year. Currently, our textiles export is USD 40.2 billion, with a growth rate of 23% as against global rate of 4.7%. Of the textiles export from India, the contribution of apparel and clothing sector is phenomenal (43%).
**Technical textiles:** Technical textiles are specially engineered textiles which the user industries belonging to wide-ranging segments such as agriculture, clothing, healthcare, construction, sportswear, packaging, sports equipment, automotives and deploy for fulfilling their functional requirements. Current market size of this industry in India is around USD 14 - 17 billion and is expected to reach USD 32 billion by 2023.

**DEMAND PROJECTIONS WITH RESPECT TO 2035**
India has always been a force to be reckoned with in the global textile industry scenario from early ages. Though it’s fragmented decentralized small and medium scale textile industries are currently facing stiff competition from China and such other nations in the liberalized global market, the traditional wisdom brought about by a rich heritage for quality textile materials seemingly not withering away, India, hopefully, will continue to have a good share of global textile trade, provided it gears up for the challenges in the times to come.

Inspite of having the largest loom capacity in the world and the world’s second largest spindleage, India’s export share in global textile market is abysmally low at 5.2% as of 2013. This only points to the dire need for increasing the quality, productivity, value addition, consistency, volume and timely delivery strictly as per the schedule committed to the buyer. Though, the overall quality and productivity of the Indian spinning mills are good, the fragmented nature and old technology being employed by the Indian weaving industry, in turn, are placing a demand for turning out a still higher quality of spun yarn without which the woven cloth production is bound to find the going to be increasingly tough. Having said that, India’s strength in the manufacture of cloth lies with its...
labour force adept at producing value added textile materials on account of which the country’s visibility in the world’s quality textile segment may very much remain a reality.

Based on the projections, it is expected that the requirement of textile goods in India and across the globe will be increasing constantly.

Overall global demand across the textile value chain is expected to grow by around 3% year-on-year in the coming years.2

The factors that would affect the projections with respect to consumption of textiles and apparels in India are its demography and changes in life style based on demographic dividend existing in 2035. This is already reflected in the faster rate of per capita spend on apparel between 2012 and 2025 (from USD 36 to 138).

2.0 TRENDS IN TECHNOLOGY DEVELOPMENT

For increase in the spindle speeds and adopting modern processing systems with automatic controls, cotton possessing a set of attributes is required. This includes a) highly clean, contaminant-free, b) stronger and mature fibres for a given length, c) low variability in fibre attributes from bale to bale, d) lower short fibre content, e) higher fibre elongation, f) lower fibre neps and seed coat fragments, g) lower organic trash and micro dust and h) higher amenability to cleaning.

These developments have grouped several of the intermittent processes into a continuous interrelated process, which had led to improved productivity and quality. Ability to react quickly to the call of the market had been the major driving force behind the technological inventions during the 1990s. Improvement in speed and hence the productivity / flexibility was the key target rather than cost reduction measures. However, these technology improvements came attached with a premium price tag, which the small and medium scale industries could not afford.

<table>
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<tr>
<th>YEARS</th>
<th>DEMAND PROJECTION FOR STAPLE FIBRE (MILLION TONNES)</th>
<th>DEMAND PROJECTION FOR FABRIC (BILLION SQUARE METRES)</th>
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<th>DEMAND PROJECTION FOR APPARELS (BILLION PIECES)</th>
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In India, during the last couple of decades, automation has taken place in almost all the processes related to textile manufacture viz., cotton picking, ginning, spinning, weaving, processing, and even to some extent in garment making, resulting in enormous gains in productivity and efficiency.
Many technological changes have happened in the textile industry, which can be broadly divided into three phases.

| PHASE I | From handlooms, high-speed spinning frames and looms, with reduced vibration levels, were developed in the 1950s and early 1960s. |
| PHASE II | During late 1960s and 1970s, rotor spinning and shuttle less looms were introduced, which brought about a major improvement in the productivity. |
| PHASE III | Since the late 1970s, changes in the textile industry that have occurred owe their origin to the introduction of microelectronics-based technology and the automation of industrial processes. |

### Automation

Developed countries like Europe and USA saw a case in point towards automating their facilities due to the prevalence of high labour cost in their countries. In India, during the last couple of decades, automation has taken place in almost all the processes related to textile manufacture viz., cotton picking, ginning, spinning, weaving, processing, and even to some extent in garment making, resulting in enormous gains in productivity and efficiency.

### Cotton picking:

Two types of mechanical harvesting equipment are used: the spindle picker and the cotton stripper. The spindle picker is a selective-type harvester that uses tapered, barbed spindles to remove seed cotton from bolls. This harvester can be used on a field more than once to provide stratified harvests. On the other hand, the cotton stripper is a non-selective or once-over harvester that removes not only the well-opened bolls but also the cracked and unopened bolls along with the burs and other foreign matter.

### Ginning

Ginning too has been automated to a great extent and futuristic techniques have been proposed to take the same to even greater heights; a machine vision-based system for on-line identification of trash objects commonly found in cotton has been shown in action which, employing soft computing techniques like, neural networks and fuzzy inference systems could classify trash objects into individual categories such as bark, stick, leaf and pepper trash types with great accuracy.

### Spinning industry

Spinning industry has witnessed advancement in the form of newer methods of spinning like, open-end spinning, airjet spinning and Vortex system. The advent of bale pluckers has made it possible to pluck cotton from several bales and make a homogeneous mixture of the same leading to a reduction in the batch-to-batch variation in spun yarn lots. It is essential that the fibre mat fed to the carding machine should be of a high degree of uniformity to ensure consistent opening and carding; this uniformity is achieved using the chute feed system, which aims at feeding a fibre sheet of a uniform packing density and uniform linear density (weight per unit length) to the carding machine. Stemming out of common sense is the realization that the mass uniformity of the card sliver is an essential criterion for good subsequent processing; the card auto-levelling system comes in handy on this count by measuring sliver thickness variation on real-time basis, and altering the machine draft so that a high consistent sliver thickness is continuously produced.

In the case of ring and rotor spinning, the speeds have increased and auto doffing has been introduced. Link winder, which has direct feeding of cops from spinning machine to the cone winder, is another major advancement paving way for reduction in manpower engagement. Moreover, online monitoring of all the machines is now possible giving the much-needed flexibility in production planning exercises. Advancements with respect to improvement of the yarn quality have come into being, recently which include splicing of joints and auto piecing in
open end frames, together with reduction in material handling due to automatic transportation of cans, bobbins, etc. The ring spindle speeds have gone up to 25,000 rpm and in open end spinning, high rotor speeds of up to 1,50,000 rpm are practicable now-a-days. The latest technology spinning machines like airjet spinning machines can produce yarn 20 times faster than that of ring spinning machines.

Fancy yarn manufacturing is one of the important areas where there is significant value addition. Electronically controlled sophisticated machines are available that have better control over the fancy yarn characteristics. Precise and fast change of the front roller speed in ring spinning gives consistent and uniform slub yarn. Electronic clearing of missing, thick, thin pile, electronic stop motions, in the chenille yarn are the few recent developments in the fancy yarn production machinery.

In the weaving sector, the technology upgrades have swept across the complete spectrum of automatic shuttle looms and automatic shuttle-less looms culminating in higher productivity. The water jet and air jet looms use, respectively, water or pressurized air to transport the yarn with multiple colour weft insertion. Implementation of electronic control in automatic looms has simplified operational routines as only the data such as yarn type, weave and width need to be input for production to proceed optimally. Quick style changes have become possible. Electronic jacquards enable intricate designs to be produced with ease. Inspection of fabrics on loom, use of optical and laser detection of warp break, reduction in downtime due to higher levels of automation and quick warp beam change have also occurred in the recent past. Weft insertion rates up to 2500 mpm are now possible, 5 to 10 times faster than what it was 20 years ago.

Automation in textile processing has encompassed the transportation of batch trolleys to the respective machines, Programmable Logic Controller (PLC) based control system for automatic completion of a process cycle, automatic dispensing / dosing of right quantity of chemicals and dyestuffs, etc., automated stock control and printing recipe, recipe prediction and computer colour matching, centralised data collection for all the machines, centralised colour kitchen to dissolve and dispense the dyes. Automation in chemical processing of textiles additionally has resulted in bringing into practice use of low liquor ratio machines, which are preferred owing to their reduced effluent loads and less consumption of water and chemicals.

Knitting, embroidery and decorating machinery have seen numerous improvements in the recent past. The new computerised flat knitting machines have minimised the need for sewing thereby creating the knitwear into a single piece. Knitting technology has seen good improvements during the past decade giving room for high speed warp knitting production of seamless garments, slitting of circular knitted fabric at the delivery point of the knitting machine itself and many more of the kind. Image processors and electronic stop motions have been characteristic of majority of the automations.

The earlier innovations in apparel manufacture have seen development of durable, faster machines, which can carry out specialized tasks, such as, laser cutting machines replacing the hydraulic die cutting machines. The subsequent modernization efforts involving introduction of computer-aided design (CAD), computer numerical control (CNC) cutting systems, and computer-aided manufacturing (CAM) have given a new dimension to apparel manufacturing. These technologies have minimized the waste, while ensuring increased production rates with better accuracy. In the assembly stage, however, technological change has so far been the incorporation of microelectronic control units to the standard sewing machines in order that they are able to handle complex tasks with increased speed and flexibility. During the initial stages of its introduction, the computer based technology did not pick up due to its high cost of ownership which reflected in increased cost of clothing. However, later, as the reliability and versatility have become field proven, more number of these machinery have been installed. Apart from the development and automation
in the apparel making processes, a lot of innovations have occurred with respect to new materials, smart textiles, etc. India in comparison to several other textile producers has a low cost of production of ring spun yarn, woven ring yarn fabric, woven OE yarn fabric and the knitted ring yarn fabric. The main reason for India’s competitive edge in woven and knitted fabrics is the ease of raw material availability and low labour cost. However, it is a matter of concern that our power cost and capital cost (interest and depreciation) are relatively higher compared to other countries that could pose a severe threat to the textile industries’ competitiveness in the global market.

TECHNOLOGY GAP ANALYSIS
A predominantly labour intensive sector, the textile industry has to adopt automation of labour intensive processes like mixing, bobbin transport, feeding the auto-winders, cop segregation, etc. Multi-fold increase in production is possible through changes in currently practiced ring spinning technology. With improvements in the strength of cotton yarns, the operational speed of looms can be increased. The development of technology in cutting and sewing is limited by the traditional sewing technology and the structure of fabrics, although better technologies are now available for the production of value added garments like plastisol printed, embroidered and art work garments. In spite of automation in several areas of textile processing, indigenous production of machinery for every conceivable segment involved in textile goods manufacture - ginning, spinning, weaving/knitting, processing and garment making is lacking. Apparel makers strive to cope up with ever-changing fashion styles by reducing the time it takes to design, produce, and deliver the goods. In this environment, technology to support such needs have to emerge as an important source of competitiveness. Advanced technologies to fulfil the extended demand for production, speed, and quality requirements for the competitive export market are required. Technologies such as robotics for automated assembly line in garment making, high speed sewing machines, pressing and fusing techniques etc. need to be made available at affordable costs. The adoption of advanced technology seems to be the way forward to improve upon these areas and meet the export standards.

<table>
<thead>
<tr>
<th>SECTOR / PARAMETER</th>
<th>PRESENT TECHNOLOGY</th>
<th>TECHNOLOGY INTERVENTION SUGGESTED</th>
</tr>
</thead>
<tbody>
<tr>
<td>COTTON CULTIVATION</td>
<td>Majority dependence on rain</td>
<td>Subsurface Drip Irrigation (SDI)</td>
</tr>
<tr>
<td>HARVESTING METHODS</td>
<td>Mostly manual</td>
<td>Automation</td>
</tr>
<tr>
<td>QUALITY OF COTTON</td>
<td>Quality declines at the end of cotton season</td>
<td>Hybrid seeds to maintain consistent quality levels</td>
</tr>
<tr>
<td>STORAGE OF COTTON</td>
<td>No proper space</td>
<td>On-farm storage</td>
</tr>
<tr>
<td>LENGTH OF FIBRES</td>
<td>Generally shorter and have wide variations</td>
<td>Produce long staple cottons with consistent quality across farms</td>
</tr>
<tr>
<td>GINNING</td>
<td>Feeding of cotton to machines done manually</td>
<td>Automation</td>
</tr>
<tr>
<td>PREPARATORY</td>
<td>Involves a number of processes for opening and cleaning</td>
<td>Hybrid seeds to maintain consistent quality levels</td>
</tr>
<tr>
<td>RING SPINNING</td>
<td>Piecing is mostly done manually, Cop content is in the range of 40 to 80 g, depending upon the count, Waste generated is high, Production rate is limited to 25 m/ min.</td>
<td>Automatic, Achieving a better package size at minimal power consumption, Less wastage, Increasing speed of the machine / a new technology multi-fold production</td>
</tr>
<tr>
<td>HUMIDIFICATION REQUIREMENTS</td>
<td>Whole preparatory, spinning and winding areas are to be humidified</td>
<td>Humidification plant integrated / free machine designs</td>
</tr>
<tr>
<td>SECTOR / PARAMETER</td>
<td>PRESENT TECHNOLOGY</td>
<td>TECHNOLOGY INTERVENTION SUGGESTED</td>
</tr>
<tr>
<td>------------------------------------</td>
<td>------------------------------------------------------------------------------------</td>
<td>---------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td><strong>PREPARATORY</strong></td>
<td>Sizing is done to single warp yarns for better weave-ability.</td>
<td>Eliminate sizing process</td>
</tr>
<tr>
<td><strong>WEAVING</strong></td>
<td>Operational speeds of weaving loom limited by the strength of warp yarns used</td>
<td>Improve the yarn quality suitably to increase loom speed</td>
</tr>
<tr>
<td><strong>HUMIDIFICATION REQUIREMENT AT WEAVING</strong></td>
<td>The entire shed needs to be humidified to achieve a better performance</td>
<td>To develop chemical or a technology that can maintain the moisture levels in the yarn without resorting to the use of humidification plants.</td>
</tr>
<tr>
<td><strong>KNITTING</strong></td>
<td>Weft knitting is predominantly used for making apparels</td>
<td>Realization of increased speeds, adoption of warp knitting technology</td>
</tr>
<tr>
<td></td>
<td>Incidence of defects of major nature is still high</td>
<td>To develop stop motions that will result in bare minimum rejections arising out of defects.</td>
</tr>
<tr>
<td><strong>ENERGY CONSERVATION</strong></td>
<td>The waste recovery plants, compressors and humidification plants are highly energy intensive</td>
<td>Energy efficient systems</td>
</tr>
<tr>
<td><strong>DEVELOPMENT OF INTRICATE DESIGNS</strong></td>
<td>Takes considerable time for preparation of the design and to produce the same</td>
<td>Faster design change and quicker production</td>
</tr>
<tr>
<td><strong>PREPARATORY</strong></td>
<td>Preparatory processes involve de-sizing, scouring, bleaching, mercerising, etc.</td>
<td>Develop a combined single step process that will make the fabric suitable for subsequent processes</td>
</tr>
<tr>
<td><strong>DYEING</strong></td>
<td>Predominantly synthetic dyes are used and in the case of polyester / cotton blends, two-step dyeing process is followed</td>
<td>Develop more natural dyes / environment friendly synthetic dyes offering a palette of wide ranging hues/shades, suitable for use with all types of fibres</td>
</tr>
<tr>
<td><strong>MEDIA USED FOR DYEING</strong></td>
<td>Media used for dyeing is water resulting in generation of effluents and rendering the already scarce commodity, namely, water, much scarcer</td>
<td>Dyeing using Super critical CO₂ or equivalent and make it suitable for all of the material variants namely, cotton, polyester, viscose, acrylic, etc.</td>
</tr>
<tr>
<td><strong>AUTOMATION IN WET PROCESSING</strong></td>
<td>Automation few; prevalence of manual work culture high</td>
<td>Improve the level of automation in this industry</td>
</tr>
<tr>
<td><strong>PRODUCTION SYSTEM</strong></td>
<td>Labour intensive</td>
<td>Automation</td>
</tr>
<tr>
<td><strong>SMART GARMENTS</strong></td>
<td>Use of smart garments is negligible</td>
<td>To develop a variety of smart garments for different applications</td>
</tr>
<tr>
<td><strong>PRODUCTION OF SEAMLESS GARMENTS</strong></td>
<td>Limited to certain designs at present</td>
<td>To develop machines suitable to produce numerous designs and patterns</td>
</tr>
</tbody>
</table>
### 3.0 TECHNOLOGIES FOR 2035

Technology change in textile and apparel industry would be driven by two growth drivers viz., economic and life style of the consumer. The economic sub-factors that would drive the technology preparedness are 

- a) increasing retail penetration, 
- b) disposable income, 
- c) number of working women, 
- d) nuclear families and 
- e) hospitality and health care.

The life-style factors that could bring about a change in the apparel features include 

- a) increased urbanization, 
- b) per capita spend, 
- c) fashion attributes such as simplicity of garment construction, 
- d) customer desired features such as breathability, comfort, water repellence, resistance to spread of flame, and anti-bacterial activity.

With increase in disposable income, consumer preferences for customized designs and sized products would replace buying off the shelf.

**ENERGY**

Improved availability of energy/power for the manufacturing units through adoption of options such as dedicated/captive power and use of non-conventional sources.

**MANPOWER PLANNING**

Training on new range of machinery and developing skilled labour force. For this adoption of virtual and factory based training programs with adequate certification tools is called for.

**TRANSPORT AND INFRASTRUCTURE**

Strengthening of major international gateways and corridor infrastructure crucial to the exports and imports of products and resources.

**TECHNOLOGY ACQUISITION**

Encouraging purchase or merger with foreign machinery brands.
Automation in unit production, cutting and stitching needs to be developed. Use of CAD to optimally utilize the fabric and minimize the wastage of the same is an urgent requirement. The art of producing seamless garments need to be perfected to produce garments of all sizes. Increased demand for customized apparel would lead to development of garments made of non-woven with very short lead times. Technology of fusing of fabrics, garment printing, garment dyeing and washing should be elevated to higher platforms as they help in production of a particular design in very small lots and thereby permit quick style changes. Technology for manufacture of recyclable garments is likely to gain momentum. Technologies for developing smart/sensor-engineered textiles would be required in a large scale.
TECHNOLOGY ROADMAP: MANUFACTURING

TECHNOLOGY AND PROCESSES

SHORT TERM (2013-2018)

- Increase the productivity of cotton cultivation by adapting drip irrigation in majority of the area under cultivation.
- Automation to be done at ginning unit to minimise material handling.
- To develop machines with integrated humidification thus minimising the energy required to a great extent.
- Zero effluent / liquid discharge in textile wet processing.

MEDIUM TERM (2018-2028)

- Hybrid seeds that give consistent and uniform cotton quality from first to last picking.
- Automatic piecing of yarn in ring spinning system.
- Technologies to reduce the number of processes involved in cotton spinning system.
- Eliminate the sizing process by improving the weavability of yarns.
- Perfection of production of seamless garments to produce garments in varying sizes.
- Smart clothes, through embedded wearable electronics.
- New technology machines for the weaving and knitting sector which can help in quick style change.
- Design and develop marine outfalls to discharge industrial effluents in a safe manner.

LONG TERM (2028 -2035)

- Production of coloured cotton with a good consistency in colour and in a wide range of colours and eliminate the necessity to dye the materials to a great extent.
- Evolve a new spinning technology with multifold production and optimum quality.
- Fully automated technology for production of tailor-made garments with a customization possibility to suit individual requirements.
- Cost effective waterless dyeing suitable for all the materials like cotton, polyester, viscose, acrylic etc.
KEY RECOMMENDATIONS

- Training farmers in using a range of improved agronomic practices including to prevent boll worm infestations
- Precision agriculture for productivity improvement
- High-yielding cotton varieties
- Contract farming and accessibility to decision making tools
- Capacity building in raw material and manpower resources including skill upgradation and development of modern and innovative tools for education
- Produce organic cotton of consistent quality
- Develop seeds for long staple fibres that can be available throughout the year
- Develop coloured cotton in variety of hues
- Implement an Indian certification system that offers traceability right from cotton cultivation to sale of end products as a means of ensuring credibility at International level.
- Encouraging modernization of machinery and increasing development and use of indigenous machinery, with emphasis on innovation and local manufacture
- Progress towards zero emission from the industry through systematic adoption of clean process techniques, including development of machines that are less water intensive
- Set-up good infrastructure for textile designing and strengthening institutional support to the garment industry
- Establishment of R&D centers for textile machinery development so as to develop textile machinery, which will address the specific problems and necessities of Indian textile industry.

POLICY ORIENTED RECOMMENDATIONS

- Draw up a dynamic and strategic infrastructure for efficient transport system that is essential for handling ever-increasing volume of exports and imports.
- Consolidation of supply chain leading to vertically integrated manufacturing

REFERENCES

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5. Final compendium Textile and Apparel 2012 – Technopak
Increased delivery package size in ring frames without increasing the power consumption and with the same yarn quality.

Reducing the number of processing steps involved in spinning.

To develop a chemical or a technology that can maintain the moisture levels in the yarn without the need for humidification plants.

Hybrid seeds, which can give consistent cotton quality throughout the year and the fibres with least possible natural variations.

Invention of a new spinning technology with multi-fold production and better versatility as compared to ring spinning.

Garments made of non-woven fabrics with a lead time of less than a week – a break-through that will result in production of garments on mass scale catering, at the same time, to customized style requirements.

Waterless dyeing for natural and synthetic fibres.

Zero effluent processes.

BLUE-SKY RESEARCH
Leather processing has remained world over as a tradition interwoven with technology activity driven mostly by market forces and consumer preferences. Science, research and innovation have by and large been undergoing changes in their own isolated spaces. Technology vision 2035 for leather foresees greater interplay of innovation driven manufacturing and leather emerging as a fashion statement.
INTRODUCTION

CURRENT INDIAN AND GLOBAL SCENARIO

Leather and leather product industry might undergo transformational changes during the next couple of decades. Technology trade coupling is bound to increase many fold from the current levels. India with a share of about 10-13% command on global supply of raw materials currently could foresee an untapped opportunity in leather sector. The value addition to raw material through technology, innovation and brand building is predicted to undergo major changes by 2035. Currently, the trade value of leather is five times of that of meat. Doubling of the global trade value of leather to meat during the next two decades is a likely challenge. Opportunity for value addition through technology will increase. Conversion of leather into value added products would still remain an activity of small and medium enterprises offering opportunities for high volume employment for relatively low investment into capital goods (namely Rs. 0.5 mil/job/year). Leather product sector would remain an industry, which connects manpower with purchasing power.

An integrated approach with clear-cut short (10 year frame) and long (20 year frame) term goals needs to be developed to effectively couple technology with trade. Hence, the foregoing analysis covers livestock, hides and skins, tanning industry, product sector, technology trends, trade and policy.

Global scenario: In the present context, tanning industry is largely concentrated in Asia and to an extent in Latin America. There are indications of industry growing much faster in Africa, which is emerging as a major sector. Countries like Brazil, Argentina and South Korea are fast moving out of the tanning segment. It is predicted that Africa might account for 20% of heavy leather (1% as of 2013), 30% of light leather from bovine (2%) and 40% of light leather (10%) by 2035. This trend will be associated with global level changes such as China and India investing in Africa, converting them into manufacturing/trading partners.

RAW MATERIAL AVAILABILITY TRENDS

<table>
<thead>
<tr>
<th></th>
<th>CATTLE</th>
<th>BUFFALO</th>
<th>GOAT</th>
<th>SHEEP</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012</td>
<td>24 MILLION</td>
<td>32 MILLION</td>
<td>94 MILLION</td>
<td>31 MILLION</td>
</tr>
<tr>
<td>2025</td>
<td>24.6 MILLION</td>
<td>38 MILLION</td>
<td>102 MILLION</td>
<td>33 MILLION</td>
</tr>
<tr>
<td>2035</td>
<td>25 MILLION</td>
<td>42 MILLION</td>
<td>109 MILLION</td>
<td>34 MILLION</td>
</tr>
</tbody>
</table>
The net effective recovery rate (after deduction of non-recovered hides/skins) is generally employed as marker for hide/skin availability. The supply of raw hides and skins remains constant over time but prices are impacted by demand for leather products. While sources of buffalo and goat appear to be promising in the next 20 years, only a marginal growth is seen with respect to cattle and sheep. Net effective recovery is expected to go up as the current proportion of slaughtered - 75% for hides and 98% for skins - will go up due to decrease in natural mortality rate, owing to better health care. Slaughter rate increase is also expected due to better access to meat outlets and pruning of stocks at farmer’s level. India could also benefit from exploring other sources of raw material such as rabbits, emu birds, ray fish skins etc.

Availability of quality hides and skins in India can be improved by adoption of promotion methods for a) stall fed goat and sheep farms, b) buff calf rearing and fattening farms, c) streamlining meat industry, d) establishment of carcass recovery centres at potential/ideal locations, e) reducing manmade defects through better curing.

As possessing raw material reserves can no longer be considered as an advantage for any country, an assessment of the global availability of hides/skins is also essential.

Estimated current global production of hides is 322 mil pcs as of 2011. Much of the growth of raw hides and skins supply has originated from developing countries in Latin America, South Asia, and Africa etc. A substantial reduction (fall of 26 mil pcs during the last 20 years) in the supply from developed countries has been recorded. In particular, Europe recorded 12 mil pcs decline from 1992. These trends indicate that developing countries would witness growth in availability of hides in the next 20 years. Overall forecast could be that developing regions may hold higher share in the years ahead though the world supplies will not go up significantly. The marginal increase is largely through buffalo hides from Asian region.

In the case of production of goat skins, global production is estimated as 434 mil pcs which recorded a growth of 185 mil pcs over period of 20 years. Nearly 95% of the global production of goat skins is from developing countries of Asia and Africa. Asian countries such as China, India, Pakistan and African Countries consisting of Nigeria, Ethiopia and Sudan have significantly contributed to the supply. It is anticipated that goat skin supply would go up in the next 20 years.

In regard to sheep skins, about 547 mil pcs are produced annually, of which developing countries account nearly 67%. With increase in growth to the tune of 40 mil pcs over 20 year period, the growth rate is not as appreciable as goat skins. The major suppliers are China, India, Australia, New Zealand, Iran and Turkey. Recent trends indicate that even in Oceanic countries, supplies are dwindling. The forecast is that there will be an increase of supplies in the next years to the extent of another 50 mil pcs by the year 2035.

INDUSTRY AND INDUSTRIAL PRACTICES
Processing Industry: This industry had been marked by a co-existence of artisanal and organized processing units. Mechanization and modernization adopted by the organized sector from time to time has resulted in improved quality. Ethnic footwear manufacturers of Rajasthan and Maharashtra, who account for less than 5% of the production, are the only dominant manufacturers in the artisanal sector today. The leather produced from Indian leather industry today, is estimated to be 2100 mil. Sq.ft (1800 mil. Sq.ft from domestic and 300 mil. Sq.ft from imported raw material/wet blue).

Organized tanning is predominantly in clusters located in the states of Tamil Nadu (Chennai, RaniPET, Ambur, Vaniyambadi, Erode and Dindigul), Uttar Pradesh (Kanpur, Unnao), West Bengal (Kolkata) and Punjab (Jalandhar), together accounting for close to 95% in the country. Cluster approach has the advantages of skilled labour; machinery capacity sharing; common effluent treatment plants; ease of chemicals and accessory availability; service engineers etc.
The pace of modernization has been tardy, in spite of having access to best technology and trained manpower owing to the present operation and management system. One of the positive aspects of this industry is its ability to convert relatively poor quality material into best quality leathers through appropriate technology. States like Andhra Pradesh are looking forward to the establishment of mega leather clusters complete with environmental safeguards – an initiative to be considered as a major step forward for this industry.

**Product Industries:** Major products made out of leather are footwear, leather garments, leather goods consisting of handbags, wallets, gloves, harness and saddle; upholstery etc. It is footwear that consumes almost 50% of the leather produced in the world.

The manufacture of leather products is systematically promoted in India as there is a value addition of 4 to 5 times over the raw material. In fact, value addition is taken as the principle goal for exports and to introduce a series of incentives and disincentives for exports.

Footwear sector currently exists in traditional as well modern sectors at varied levels of operation. Domestic market is largely served by traditional/decentralised sector with sandals, chappals and ethnic footwear. Footwear clusters are located in Agra, Kanpur and Kolkata. In the case of exports, production emanates from modern units with varying capacities. An assembly line system which is employed as the style of production, throws open large employment avenues for women workers in south India with 90% of total labour in modern shoe factories, thus contributing significantly to social development of region. Of the 909 mil pairs of leather footwear currently produced (2013-14 data), 150 mil pairs go for exports, mostly in the form of shoes. Leather footwear consumption in India is predominantly in the form of chappals and sandals, ethnic products such as Kolhapuri and Jutis. Per capita consumption of footwear is likely to go up from 2 to 3 pairs in the next 10 years and to 4 pairs by 2035. Compared to non-leather footwear, the market share of leather footwear in domestic trade is quite low and this trend is expected to widen in the future. There are indications that this trend would prevail globally.

Comparison of the trends in the global scene indicates that as of now, lower segment of the market is dominated by China, while premium segment is dominated by Italy. Vietnam is fast catching up at global level as major contract manufacturing country for reputed global brands. Consumption of leather footwear at global level may not go up significantly going by the current trends. Non-leather footwear with variety may take a center stage in the years ahead. There is a need to develop materials for this sector. The increase in the market will be largely contributed by Asia and Africa, where income and population are rising. Use of footwear (leather plus non-leather) is likely to double in the next 20 years at global level. In this growth, leather footwear may not gain much share. Leather footwear is likely to retain mostly high priced segments only and slowly emerge as a premium product.

Garment is a highly leather intensive commodity, global market share has increased, especially after the decline of fur coats based on endangered species. Indian specialization in leather garment manufacture through export oriented clusters in Chennai, Noida, Mumbai and Bangalore (production capacity of 16 million pieces) has been considered advantageous. Domestic market in leather garments is negligible as more than 90% is currently exported. Leather garment probably would become a high value product with a low volume production. As of 2014, 120 million pieces are manufactured and traded globally of which more than 66% is priced at less than US$ 35. This market segment will further diminish and technology and unique customer values would start dominating. By 2035, main market for leather garments would be the fashion industry.

Leather goods are a very broad category with a mix of utility and fashion products. India also produces leather upholstery – sofa seat covers, car seat covers etc. Production segments are in Kolkata, Delhi and Chennai, with production capacity of 63 million pieces annually, of which 80% goes for exports. Sub-contracting of leading global brands, which

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Technology and innovation content in the manufacture and marketing of leather goods is likely to increase significantly during the next two decades.
enable the enhancement of value, is the mode of operation. With the infrastructure created for fashion goods, India is becoming a major design base for catering global market, particularly taking the advantage of ethnic designs. Production of upholstery is likely to strengthen in the years ahead.

Major categories not included above are the gloves and saddlery. Gloves include all categories like fancy/fashion gloves, sports gloves, and industrial gloves. India is the fourth largest exporter with annual production capacity of about 52 million pairs for industrial gloves itself. India is positioned as the third largest exporter of saddlery and harness to the world, accounting for a share of 9.01% in the global saddlery import of US$ 1224.94 million as of 2012. This sector is not likely to grow in the long term.

A comparison of the global trends indicates that China, Italy and France are major players. Market is likely to witness changes giving way to high fashion articles rather than cheaper products. Leather accessories form a class of products with a potential for growth of market demands. Design features of these products offer unique opportunities for value creation of the consumers. Unit value realization from leather as accessories is likely to increase much higher than other products including footwear. Technology and innovation content in the manufacture and marketing of leather goods is likely to increase significantly during the next two decades. Countries like India which has a large SME sector stands to gain through advanced research and design capability.

TRADE OF INDIAN LEATHER SECTOR
Trade involves two angles, viz., domestic and export. With dominance of non-leather footwear, complexity of domestic market is likely to change. Premium footwear is likely to find opportunities in the years to come. Growth projections of this industry are dominated by export market. The level of exports is around USD 5.91 bil for the year 2013-14. Except for a few years in recent past, export from leather sector in India has witnessed a consistent growth and in the year 2011-12, recorded close to 23% over the previous year. The industry, thanks to the technology support, has transformed from raw material exporter to an 80% finished product exporter. 20-25% of the export is accounted by finished leather and footwear components – materials that have a huge value addition potential. Indian leather importers are significantly located in Europe and China. Germany is a consistently major trading partner for India, with a share of 15%. However, one of the major concerns of India, is the share in global market, which is as less as 4% as of 2013-14 (USD 170 bil. of global market). India is finding it difficult to compete on cost with China and on brand image with Italy. The combined share of China and Italy is around 40%. Other competitors for India are Brazil and Vietnam. The model of operation of Indian leather industry is the focus on medium segment of the market, wherein efforts to consolidate the base and exploring new market avenues is being progressively attempted.

While the industry exports finished leather products, it imports hides/skins, leather, chemicals, machinery etc. However, the advantage in favour of this industry is that the imports are hardly 15% of the exports, while the same in China and Italy is around 40-50% (in value of exports). This is because, Italian leather industry imports leather for value addition prior to export. The import of hides/skins by Indian leather industry, in spite of favourable policies is not significant. Resource poor nations such as South Korea, Italy and Turkey had become important players in leather trade while resource rich nations such as Brazil, Argentina, India, Australia and USA are less prominent with respect to share in the global trade.

Based on the analysis, the goals set for Vision 2035 are:

• Establishment of integrated leather clusters and green parks linked to raw material sources and valued added product units needed
• While footwear consumption will double, leather will get hardly 10% of the share, therefore current growth profile based on men’s footwear and specific European markets need to change
• Domestic market for leather products will grow
• Leather goods, foot care products, children footwear, upholstery to become
Technology vision 2035 for leather foresees a transformation of a byproduct of meat sector into a technology driven industry, where S&T led innovations, for the first time in its long history, are likely to drive the next paradigm of change and those who enjoy access to technologies and innovations would emerge as leaders. There is an opportunity for the rise of India in global leather sector.

nich value products
• India to become hub of ethnic design products
• Technology backed growth of leather industry in India should be seen as an advantage

DEMAND PROJECTIONS FOR 2035 AND METHODOLOGY FOR ROADMAP
A detailed roadmap based on current and future trends on raw material and products has been put in place. This includes
a) technology pathway to enforce and comply with environmental regulations that may come from time to time, b) reducing the carbon footprint of the industry through development and adopting of appropriate technologies, c) adopting an economy of scope model of marketing to ensure technology based value addition to leather, d) technology for developing various products and thus be in a position to provide a new product mix, e) technology to develop products which would not only meet consumer preferences but also enthuse in them newer needs, f) ensuring highest level of compliance to animal rights and protection through new technologies, g) technology for meeting regulatory norms and finally h) wading the competition from non-leather. These technology drivers are detailed below.

Enforcement and compliance to environmental regulations: By 2035, it is expected that enforcement of environment regulations and compliance to strict emission norms would force changes in technologies adopted in leather processing.

PRIORITY FOR 2035 ARE LIKELY TO INCLUDE

1. Technology simplification coupled with economic gains so as to ensure adoption of in-plant control over end-of-pipe treatment methods

2. Assisted and/or aided transport of chemicals and auxiliaries into skin or hide

3. New methods of cross-linking and long term preservation as alternatives to chrome tanning

4. Conversion of solid wastes generated in leather processing units, meat industry and product industries into value added products, including amino acids, cosmetic and pharmaceutical products etc.

5. Eliminating nitrogenous and sulfide gases through shift from chemical to bio-processing and incorporation of aqueous finishing to eliminate volatile organics

6. Adoption of appropriate technologies to reduce wastes from chemicals employed for aesthetics and value addition by shifting such process to product industry rather than process industry

7. Adoption of processes, where biodegradability of leather products can be ensured under set conditions so as to avoid solid wastes from used products

i. Enhancing the atom and energy economy of the process, so as to reduce liquid, solid and gaseous wastes, leading to the doubling of weight of leather obtained per ton of raw material (currently 350 kg of leather is obtained from 1000 kg of raw material)

ii. Shifting away from the “Do-Undo” principle of leather processing through rationalization of unit processes and unit operations

iii. Technology simplification coupled with economic gains so as to ensure adoption of in-plant control over end-of-pipe treatment methods

iv. Waterless processing or solvent recycling
Carbon footprint of leather sector needs to be assessed in terms of the emissions of greenhouse gases at the time of storage of materials, manufacture of leather and products, waste management as well as the global transport of materials. Literature on carbon footprint from leather footwear indicates a wide range from 10 to 100 kg, leaving enough scope for technology aided reduction, such as enhancing energy economy of the processes. Cost of not processing hides and skins into leather in the form of carbon footprint might also form a consideration. Carbon footprint analysis of global leather trade is likely to affect trading and marketing more than even leather processing technologies.

Models of marketing: Currently, global leather trade includes marketing through both merchandising and branding segments. By 2035, the share of merchandising market segments is likely to decrease. Terms like labour arbitrage is likely to yield way to technology and expertise arbitrage in global trade. Segments of global tanning industry supported by technology to suit environmental regulations might derive advantage of technology preparedness. International brands of leather products could sustain their brand value only when manufacturing is made without compromises to environmental regulations. Finishing activity is likely to shift from tanneries to leather product units. Global leather processing activity would demand environmental viability. Therefore, leather processing activity is likely to shift to large and medium scale manufacturing units with economies of scale and ability to comply with regulatory norms.

On the other hand, conversion of leather into leather products is likely to derive advantages from economy of scope. Small and medium enterprise in manufacturing and marketing would gain through branding and formation of marketing companies. India, which currently operates both economy of scope and economy of scale, with technology driven products such as ladies and children footwear; safety and occupational shoes, smart upholstery and garment leathers, high end utility gloves etc. is likely to adopt the economy of scope model. Under such circumstances, the translation of the industry from tradition based to knowledge and innovation driven is likely to happen. Leather product export market would then be independent of access to market. It is foreseen that technology niche would drive the Indian leather export.

Product mix: Global leather trade currently consists of both high volume with low value as well as low volume with high value segments. Volume segment with low value is likely to lose to the products from non-leather materials. Share of non-leather footwear is likely to increase from the current levels by at least 50-70%. It is estimated that 1.7 billion square meters of upper materials are required for covering the human feet of the world as of 2010. Of this need, leather is able to meet currently only about 45-50%. It is not unlikely that the share of leather as upper materials used might decrease to less than 25% by 2035. Products where low levels of expertise and innovation are required seem to be a major product mix of the global industry today. The compliance to various regulatory norms is likely to push-up the cost of manufacture of leather. Therefore, unless leather processing industry, through new technology paradigms is able to gain high economic returns from by-product industries, it is likely that non-leather would replace leather from the low priced market segments. Products, which conform to the use of processes that meet the highest levels of ethical norms, environmental and social stipulations, and are declared safe for use for children and elderly alike, would dominate. Innovation and design driven products such as women’s footwear, children shoes, and safety products will need to dominate the market. Innovation driven products for aerospace, intelligent garments, upholstery with smart properties will need to be developed.

Leather sector is likely to undergo a major transformation from a material and market driven industry to a technology and innovation driven sector. Expertise and innovative ability of human resource capable of transformation are likely to gain high importance. Newer programs at the undergraduate and graduate level such as those on design innovation, fashion intelligence and strategic material forecasting
would be required to provide a new generation of manpower ideally suited for the industry at that time. India could foresee a special status in the new technology paradigm of 2035, by investing judiciously into a) research, b) technology development, c) expertise build-up, d) compliance to global ecological and social norms, e) building national capacity for design innovations and f) brand building.

**Consumer preferences:** Likely to be dominated by fashion, utility, safety and ethics, the market for customers who would want unique product definitions will dominate leather. Customization of product features is expected to be the norm of the future. This would then require the leather product manufacturers to innovatively build products with properties that were ‘hitherto unknown’, so as to create a need rather than cater to a need. Health care sector, with footwear for specific health conditions, garments which can deliver drugs, monitor health condition etc. would be another area for leather to dominate.

Pressure groups fighting for animal rights protection are likely to mount and exert influence on global leather trade. It is true that there is an increasing trend of vegetarianism in developed countries, but the meat consumption is unlikely to decrease. With improvements in purchasing power in developing and emerging countries, meat consumption might undergo little changes. Even, if vegetarianism increases in the world, death of domesticated animals cannot be overcome. As long as human civilization continues to rear domesticated animals, there would be supply of hides and skins and it would remain as a by-product of the livestock industry. The by-product nature of the leather industry alongside the growing market and value realization from leather is likely to increase value for hides and skins. Slaughter of animals for hides and skins from reared animals is likely. This is likely to meet several social objections. Organized animal farming for skins and hides from non-conventional sources might emerge as an industrial activity in some countries. Application of modern techniques like stem cell for growing skin like materials in industrial environments may be considered by 2035, if the value realization from leather as a fashion statement becomes high enough.

For the safety of mankind, any material that is subjected to mass production is likely to encounter regulations relating to health and safety, solid, liquid and gaseous discharges etc. By 2035, technology for production of niche products, which are customer specific, is expected to be coupled with environmental technologies to avoid discharge of any kind. In-plant processes for optimal use of chemicals, raw material etc. will also be in force. As products are meant for an elite class of customers for whom the highest level of ethical and regulatory compliance is mandatory, it is expected that industry would switch over to voluntary compliance than regulatory. Technology for innovative products will be coupled with technology for waste-less process. Biodegradable leathers, which do not leave wastes after product usage, are likely to be mandatory.

**Non leather:** By 2035, several conventional uses of leather would have been replaced by non-leather. This is likely on account of a) inelastic supply of raw hides and skins to meet new market needs and bulk demands b) higher costs of production than those of synthetic equivalents and replacements and c) ability of synthetic materials to meet leather-like features. Challenges from synthetics can be met through a) combination with other natural fibres such as jute etc. and b) technology / innovation driven products which are unique of hides / skins.
GLOBAL AND DOMESTIC TRENDS AND TECHNOLOGY GAPS

Livestock: Leather industry takes birth from livestock/animals. One of the major challenges in analysis of livestock and subsequent availability of fallen carcass for the leather industry arises from the decentralized character of the animal farming process in the country. Simplification of existing technologies such as those of radio frequency identification currently adopted for endangered species would lead to its adoption in the case of domestic animals as well. Such technology application would provide details such as animal stock availability, feeding and maintenance patterns, information on the eventual death/slaughter, thus making the process of collection of raw material easier, quicker and above all transformation of predominant part of livestock into raw material for the leather industry.

Tanning chemicals: Consumer preferences for softer products and their ever-growing concern for safety and environment have resulted in a call for change of tanning system away from chromium. Technologies for replacement of chromium by other mineral tanning materials or natural products have not been forthcoming. Such replacements by 2035 are not likely. With the growing period for vegetable tanning materials such as wattled close to 10 years, genetically modified products will be required to reduce the growth periods and be in a position to meet even 10% of the global demands on tanning materials. Issues such as deforestation also need to be addressed. One of the forthcoming technologies would be the synthetic analogues to vegetable tanning materials. Other organic tannages such as those based on aldehydes will be phased out owing to reported toxicity of the aldehydes. The 100°C factor for shrinkage still remains elusive for most tanning agents. One of the options considered ideal by researchers is the mixed metal tanning systems, wherein the use of chromium(III) (as oxide) can be reduced to less than 25%, so as to be just good enough to provide desired shrinkage temperature. Mixed metal oxides of chromium with zirconium, phosphonium and iron have been reported and can be expected to lead way, as they not only reduce the use of chromium but also provide for fullness, natural colours etc.

There are also reports that chromite ore processing residues generated by the chromite beneficiation industries, which currently are immobilized in secure landfills will force the chromium industries to be...
phased out. This has also led to an increase in the price of basic chromium sulfate. A major segment of the market seems to have adopted manufacture of basic chromium sulfate from waste products such as spent chrome tanning liquors. This is also an indication for the leather industry to adopt chrome free tanning where-ever possible.

By 2035, technologies for conversion of leather into leather products might opt not to deploy heat-setting methods and therefore demands of shrinkage temperature above 100°C might decrease.

Nanotechnology has paved way for targeted drug delivery by way of drug encapsulation within defined matrices, which carry target specific binding sites. This technology can lead to metal ions (which are toxic) giving way to naturally found metal oxides encapsulated within polymeric matrices that can specifically bind to collagen active sites, thus providing for an enhancement of thermal and mechanical stability. Research also would lead to modifications to skin collagen itself, such that enzymes involved in collagen degradation pathways cannot recognize collagen, thus leading to enzymatic stability of collagen – one of the objectives of tanning.

Consumer preferences and eco-norms are expected to go hand in hand in the future. There are calls for developing biodegradable leathers. Research in India and elsewhere indicate that the vegetable tanned leathers are hard to biodegrade, followed by chromium. This also calls for changes to tanning methodologies, so as to provide leathers, which are easy to biodegrade under given conditions. Dialdehyde-polysaccharide combinations are expected to perform well under such conditions.

In essence, research in tanning has equipped the leather industry with a basket of technologies ready for end use. Consumer preferences as well as cost and other ecological considerations might favour the non-chromium based tanning technologies by 2035, but it is not likely that cationic mineral systems will be replaced by organic tanning agents including natural vegetable tanning materials.

**Leather Auxiliaries:** Classified as bulk and specialty products, this industry is a predominant driving force of the manufacturing sector. Increasing knowledge on the fact that bulk chemicals contribute to emission loads and specialty products to presence of harmful substances, which are constantly brought under various import bans has forced the auxiliary industry to adopt changes. A large amount of bulk chemicals would be replaced with robust enzymes, such as in the case of unhairing and fibre opening. This shift would be predominantly due to environmental constraints. In a similar manner, leather processing methods, which generate or use neutral salts would have to be phased out, so as to avoid creating salinity to river and soil. Leather auxiliaries such as those used in re-tanning of leather containing neutral salts will have to undergo process modifications to ensure salt free products. Leather as a commodity is expected to undergo a vertical split in trade, with one segment focusing on bulk products for common use such as footwear and garment and the other on specialty niche products such as gloves, saddlery, women wallets and upholstery. Lifestyle leathers such as those used in hiking, biking etc. will also find niche markets. These high performance leathers are reported as the pinnacle of technical achievement, with auxiliary manufacturers putting their best R&D efforts to provide for properties hitherto not found with leather.

Smarter leather, which can act as power supply carriers, deliver drugs etc based on smarter auxiliaries is expected to occupy premium leather trade. Leather is a product of an intelligent material – skin, which when present on the animal had performed several intelligent functions such as temperature control. There will be an increasing trend to ensure that these intelligent functions, which involved a large number of nerve connectivity to the brain is either preserved or is externally provided to the leather through auxiliaries.

In the case of bulk leather, cheaper auxiliaries that can meet the demands of fullness and softness will be required. With customer demands on knowing what chemicals go into their leather, as well as a need to meet
REACH or similar norms, there will be a trend to classify such chemicals as generic products. These products would be simple enough for a large tanner or a cluster to produce in-house, preferably using wastes generated in the tannery employed as raw material. There will also be a niche market for one-shot auxiliaries, such as those which provide multifunctional property of retanning with fatliquoring.

Dyes are expected to dominate the auxiliary trade. Products, which have good fastness and can withstand user dictated usage conditions will be predominant. This includes the use of reactive dyes. Green-mark, which is expected to dominate consumer minds, would pave way for the use of natural dyes in leather; similar to the case of textiles. Usage of pigments would be predominantly for lower end products as niche products would require leathers to show off their natural hair pattern and blemishes. Pigments and finishing auxiliaries, which are transparent and yet can cover defects, as well as that can provide specific functions such as cool factor; camouflage properties, thermo-chromic effects etc. are likely to dominate both fashion and smarter leather product markets.

Chemistry of fatliquors could find a change from sulfonation. Products, which are amphoteric, are likely to be preferred. Consumer demands for flame retardance, water resistance etc. would lead to a new range of fatliquors. Though quite young, nano-emulsions could occupy a small portion of the leather lubrication products.

In all these auxiliaries, manufacturers would need to develop technologies to ensure the absence of banned substances, or would generate toxic substances such as Cr(VI) on usage.

Preservatives currently employed in the initial stages of leather manufacture as well as during finishing would find constraints relating to their toxic effects. Biocides and natural product based anti-fungals are likely to dominate this part of the industry.

Wastes: Two major constraints faced by the global leather industry are low levels of technology changes and secure and cost effective management of wastes.

Zero liquid discharge methods, which are slowly becoming mandatory, would undergo change towards zero liquid discharge through in-plant control methods alone, rather than in-plant control and end-of-pipe treatment. The compliance is expected to change from statutory to voluntary as cost of water as a raw material will be high. Technological options, which have currently remained at the laboratory level such as process integration; reversed leather processing etc. will have to be adopted by the tanners.

Safety at the workplace will gain relevance. Odour abatement, control over VOC and other gaseous emissions, noise etc. will gain prominence. In fact the release of greenhouse gases and sludge from the waste treatment plants itself will be an issue to tackle.

Atom economy in leather processing being low, tanners who adopt such processes with a very high atom economy, will end up occupying the heights of the profit table. Choice of chemicals, their compatibility to each other; process machinery, which promote better diffusion etc. will become critical. With biological processes reported to provide for a higher area yield compared to conventional processes, tanners will be prompted to adopt such methods as leather is sold by area rather than weight.

Technologies for conversion of the wastes (650 kg per ton of raw material) into value added products are currently available. Tanners will either have to turn to producers of such value added products or will have to integrate themselves with such producers. Biological disintegration of wastes in the tannery premises, leading to generation of bioenergy for use in tanneries itself will be one of the options to look ahead.

Other matrix components of skin or hide:
It is widely known that potential economic values of several minor matrix components of skin or hide are not being realized in the manner in which skin or hide is processed in tannery sector. Leather processing sector has operated with a mindset of a by-product of meat industry and had not focused in gaining values from high value and minor matrix
components of skin or hide. Economics of survival could force tanning sector to explore technologies for fuller realization of other by-products of skin or hide. Life Cycle Analysis concepts could promote the global leather industry to adopt closed cluster or network, where animal husbandry systems, chemical manufacturers, tanners, product manufactures and by-product utilization industries could co-exist. This provides for newer approaches to management of chemicals, raw material and wastes, thus leading to zero discharge clusters.

3.0 TECHNOLOGIES FOR 2035

TECHNOLOGY DRIVERS, CHALLENGES AND INTERVENTIONS

Any industry would want to maximize its profits. In the case of leather industry, value addition to the raw material, which will continue to be procured by weight and sold by area, would depend on technology employed to upgrade the available raw material, conversion of any type of material into premium products and above all maximizing the area yield. Technologies that will enhance the area of leather, such as biotechnology oriented techniques for operations prior to tanning and mechanical operations after crusting will have to be employed.

One of the key concerns of a modern leather factory of 2035 would be the time of processing. Current schedules of a minimum of one week for processing would need to be reduced to a day or so through appropriate adoption of technology and mechanization/automation. With availability of quality manpower on the decrease for such wet-end operations, a complete automated tannery with adequate in-process quality control measures would be required. Tanneries and product manufacturers will also benefit from clustering, where leather manufacturer can understand the property requirements of the product manufacturer and work accordingly.

The transition from a by-product of meat industry into an industry making value added products comes with challenges on the ethnic front as well. Leather industry will have to work on its carbon credits. Clustering of the leather industry in areas where forward and backward linkages to auxiliary manufacturers who utilize their wastes for manufacture of chemicals and meat industry, which can provide hide/skin as green/chilled will obviously be the way forward. Industry will also have to implement adequate measures for reduction of gaseous emissions and adopt technologies, which will enable them to obtain high atom economy and low carbon wastage. Highest level of operational health and safety will also have to be implemented.

Creation of green technology parks and its linkages to innovation hubs would be required to be ahead of time in technology advancements for the industry. These parks should have facilities for proper sourcing of collagenous wastes of the leather sector, process them and forward to pharmaceutical/cosmetic industries which can convert them into value added products. Direct linkage between these two industries, so as to churn out collagen product industries, as by-product utilisers of tanning industry would be required. In essence, these green parks will implement a cradle-to-grave approach for leather.

One of the major challenges that the leather industry would encounter to reduce its carbon credits is to find adequate use for its non-collagenous organic matter. An analysis of the technology related challenges, and a roadmap to overcome such challenges over a period of time so as to be ready with an industry implementable technology by 2035 has been analyzed. For this, technology solutions to current problems, which can be
achieved in the next 5 – 7 years have been classified as short, 10 – 15 years as medium (do-how and show-how period) and around 20 years as long (technology upscaling, do-how and show-how period).

These organic materials will also have to be adequately transformed into value added products. Forward linkage with industries who can convert these wastes into products is essential.

In short, tanning industry of the future will be an integrated enterprise with linkages to raw material supplier and solid waste utilizer, one which has a zero discharge policy for water – completely dependent on inplant methods and where no gaseous emissions occur.

TECHNOLOGY INTERVENTIONS

Property related: where a constant innovation to provide consumer preferred properties from available raw material rather than raw material of choice would be the focus. With growth rate of cow and sheep the ideal raw material for several applications not in favour of India, Indian leather industry would need to either import raw material of choice either as hides or skins or as leather for conversion into products. Under such circumstances, the price of the final product would be dependent on the supplier rather than the leather producer. It would be ideal for India to innovate processing methodologies such that any leather can be produced from any material, especially when a dearth of raw material is not envisaged for India.

In the product arena, the growth of footwear into foot-care and personalized products would bring in cross fertilization of ideas and methods of uplifting the hidden properties of hides/skins for such products will have to be worked up. This would enable India to capture the niche market as the normal footwear market is expected to give way to synthetics. Concentrating on intelligent products and niche markets such as upholstery is needed. Upholstery for aircrafts, waterproof leathers for aviation industry are some of the niche products with high value.

Cost-benefit ratio: In spite of fluctuations in trade, the most innovative tanner would be one who is able to enhance his benefits at reducing costs. Innovations in chemical and raw material utilization (reducing their cost contribution to overall cost), environmental management, manpower etc. will be more prevalent.

Societal: Country would want the industry to survive, more so as a large number of people are dependent on this industry indirectly. Animal husbandry systems would want leather sector to survive as there are no other good options for disposal of raw skins/hides at a premium price. Industry would need a corporate environmental commitment. The best option forward for the industry is to gain global acceptance through better environmental and quality management.

External factors: Synthetics, economy and time would be three major issues to deal with. These are directly related to the disposable income available to the consumers. The category of leather and leather products is promoted as an export commodity for India, as the disposable income available with the consumer in India is not high enough to afford premier quality of leather products. India, today adopts both the ‘economy of scope’ and ‘economy of scale’ models, where high value niche products are exported and low value products such as common footwear are domestically traded. Even in the case of footwear, technological intervention to produce leather and footwear at a price economically acceptable and within minor variations to that of synthetic (non-leather) footwear would be required.

The likely situation by 2035 could be analyzed from three scenarios of disposable incomes. First scenario would be that of disposable incomes of consumers remain as that of 2013 whereas human population continue to rise on the projected lines by 2035. Given the social pressures, environmental regulations would continue to be stringent and even more in the years ahead. Tanners will have to adopt technologies for in-house or end-of-pipe treatment of wastes, leading to cost of manufacture of leather remaining high. This would lead to leather occupying spaces of niche consumer demand and the market for the same would be in regions
## CHALLENGES AND TECHNOLOGY SOLUTIONS

### SHORT TERM

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<tr>
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<td>Products – competition from synthetics</td>
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<td>Niche products with technology superiority, natural product advantage, devoid of ethical and social issues</td>
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<td>Solid wastes</td>
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<td>Atom economy to ensure complete utilization of raw material Integration of by-product industry to tannery clusters</td>
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### MEDIUM TERM

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<td>RO treatment, solar evaporation</td>
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<td>Gaseous emissions</td>
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<td>Cost</td>
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<td>Machinery</td>
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#### TECHNOLOGY SOLUTION

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<tr>
<td>Cost reduction through in process control and monitoring</td>
<td>Cost reduction through avoidance of end-of-pipe treatment</td>
<td>New raw materials and raw material independent products</td>
<td></td>
</tr>
<tr>
<td>- Ultrasound and other technologies to aid penetration</td>
<td>- Newer solvents for enhanced penetration</td>
<td>In process control, fuzzy logic based fault diagnosis, reduced time for penetration, enhanced recovery of solid, liquid and gas wastes for value addition</td>
<td></td>
</tr>
<tr>
<td>- Machinery optimized for clean recovery of wastes</td>
<td>- Nanoproducts for improved diffusion</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### LONG TERM

<table>
<thead>
<tr>
<th>Challenge</th>
<th>Technology Leads</th>
<th>Drawbacks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ethical and Social issues</td>
<td>Major level compliance</td>
<td>Limited to few tanners</td>
</tr>
<tr>
<td>Process duration</td>
<td>None</td>
<td>Limited by chemistry</td>
</tr>
<tr>
<td>Human resource</td>
<td>- Workforce driven operation - Guided by their skill and intuitions</td>
<td>Limited to skill of workforce, gained only through experience</td>
</tr>
</tbody>
</table>

#### TECHNOLOGY SOLUTION

<table>
<thead>
<tr>
<th>Challenge</th>
<th>Short term</th>
<th>Medium term</th>
<th>Long term</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regulatory compliance to norms meets indirect ethics and social compliance</td>
<td>Niche markets provides voluntary rather than regulatory compliance</td>
<td>Products based on available raw material, integrated processing clusters, niche products and niche markets</td>
<td></td>
</tr>
<tr>
<td>Diffusion chemistry to reduce process duration</td>
<td>Fixation chemistry to be innovatively managed to reduce process times</td>
<td>Product size not be a limiting factor to diffusion Fixation through coordinate and covalent linkages with faster kinetics</td>
<td></td>
</tr>
<tr>
<td>Adequate training of new manpower on areas such as machinery, design, quality assessment</td>
<td>Robotics for work management, non destructive and online testing facilities</td>
<td>Reduced dependence on intuitions. Skill dependence only for innovation in process and product space</td>
<td></td>
</tr>
</tbody>
</table>
where the disposable income available with the consumer is good enough to afford leather products. It means that export focus will continue with low/poor off take in the domestic market. It is quite unlikely scenario.

The second scenario would be that of disposable income available with the Indian consumer increases, say by 25% from the current. Under such circumstances, niche leather footwear would find market domestically, while export market would still continue. Non-leather footwear may dominate the day-to-day use footwear markets. The mindset of the consumer to procure economically viable products for day-to-day use and high end products for once in a while use, would retain the consumer requirements of leather footwear to less than 2 pairs per year per person. Under such circumstances, leather footwear would move into niche use segments rather than common use footwear.

The third scenario is that of the disposable income increases by 50% from the current. Indian leather industry would move into the 'economy of scope' model rather than the 'economy of scale'. Under such a situation, niche/technologically superior leather products will find significant market in India, particularly for elite and enlightened consumers of India. These products may have to be in the form of 'personalized to the end user' and satisfying the ethical and other social norms. Going by the current assessment of population increase and rise in the disposable incomes by 2035 in India, the market for leather products is quietly likely to take the shape of second scenario as envisaged above.

**Manpower:** Wet processing involving a large amount of hands on work is classical of leather processing. Availability of shop floor workers for such activities would continue to diminish. Industry may have to adopt automated systems for bulk activities like initial preparative steps and devote quality manpower for areas where the aesthetics and value of leather is amplified. Products like footwear would benefit from high level automation.

### 4.0 RECOMMENDATIONS

**DIRECTIONS FOR STAKEHOLDERS**

It is a recognized fact that the future of wealth creation in global economy is connected to knowledge creation system. For instance, innovation in processing or product manufacture is directly connected to how well one can overcome competition. In the years to come, the ability of leather industry to wade away competition from synthetics will crucially depend on its ability to take forward its science, technology and innovation skills. This could be for performance upgradation or even cost reduction in a normal product. Amongst the global players in leather, it is foreseen that domination of countries that have access to materials and market will be reduced if countries that do not have such access adopt knowledge dependent economic growth profile.

Challenge to the leather industry would be source ‘all that is available’ rather adopting the ‘all that is made available’ format. Leather industry may need to intervene and integrate with meat producers and organized livestock farmers to move origin of hides/skin supply from farmer lands to convenient organized locations.

A shift in economy drivers from access of raw materials (past) to access and control of market (present) to access of creation of consumer values through applications of knowledge and innovation is envisaged. Specialty products, which enable the “elite” to distinguish themselves as special owners, is a key element to creation of consumer values. Indian leather industry while enhancing its current strengths in areas such as raw materials, human capital, expertise base, R&D
base, institutional strength, environmental preparedness, fashion forecasting and design forecasting needs to venture into areas such as gaining access to low cost capital, hardware support to adopt innovations, labour productivity, technology culture in tanning and product industries, creativity linked to customer preferences, brand image and finally ability to create an innovation driven product market.

A conscious decision on whether to remain as an industry for mass market or move completely into a niche market needs to be made. While mass market will be determined by the economy of scale, the niche market would operate on an economy of scope model. In the economy of scale model, R&D would need to focus on cost reduction, through a) cutting down the cost of hides/skin to less than 25% of the final leather; b) reducing the cost of chemicals, water, energy etc. through appropriate management, which enhances the atom and energy economy and adoption of in house made generic products, c) reducing the cost of waste treatment by adopting newer technologies, and generation of energy and value added products from wastes – essentially a process of continuous innovation to enhance the value per square feet of leather, through cost reduction. In the economy of scope model, an understanding of customer preferences to smarter products, adopting innovative elements to lead the customer to new products carrying properties hitherto not imagined by the consumer, reducing the time from conception to release in market and adopting changes frequently is needed. For both these models to be successful, trained technologists and innovators need to gain command of global leather sector.

POLICY CHANGES AND ETHICAL ISSUES

India has invested significantly into leather sector through promoting polices, developing technologies and human resource and exploring new market linkages. Leather is perhaps one of the few sectors in which India commands a global respect as a technologically-advanced country with large untapped potentials. When a forecast is made that technology-trade coupling is likely to increase significantly, there is an opportunity for India to emerge as a major player in leather sector.

The Council of Scientific and Industrial Research, through its Central Leather Research Institute, which can network with expertise available in other laboratories generally, develops technologies that are 5-10 years ahead of its need so as to be in a position to meet the exigencies in time.

STRATEGIES AND POLICY INTERVENTIONS

Strategy for development is carried out through programs, which are largely funded by government agencies. The programs cover infrastructure development, human resource development, support to artisan sector, modernization, promotion leather cluster/complexes, funding common effluent systems etc. R&D is the backbone for all the efforts, which is provided through the activities of Council of Scientific and Industrial Research. Trade related efforts are handled by Council for Leather Exports. The thrust of the policy is to make leather industry strong, vibrant and operate on balanced growth of all sectors.

There are two dimensions for the policy framework. These are industrial and trade policies. Industrial policy pertains to balanced growth of all regions and all segments of the leather sector. To cite an example, various categories of leather products were reserved for small scale sector till recently so as to ensure the balanced growth. In the case of trade policy, it relates to exports and imports. Entire orientation of export policy is to promote value added products for export. Towards this goal, there were bans, quota restrictions, duties on the exports of low value raw materials etc. To promote value added products, series of incentives such as cash compensatory support, duty drawback, airfreight subsidy, Rep licenses, tax concessions have been offered. In the current context, with the emergence of WTO, many of these restrictions/incentives have been taken off. However, the policy continues to promote fully fabricated products. Imports of raw materials and leather are allowed free of duty to spur the growth of export segment, while imports of chemicals and machinery are allowed at concessional rates of duty to support the growth.
TECHNOLOGY ROADMAP: MANUFACTURING

BLUE SKY RESEARCH

ENVIRONMENT
- Environment management to be needed only for biodegradation of used leather products as process methodologies in tanneries and product units to resort to zero waste process techniques.

PRODUCTS
- Products to be developed from crust leathers, finished in product making units according to the expected value in market chain – incorporating elements of intelligence to the product.
- A constant innovation to think ahead of consumer dreams about a leather product.
- Fashion oriented products to be developed from unfinished / non-pigmented products rather than heavily pigmented material.
- Design innovations to optimize material usage, lower cost and convert lower ends into lifestyle, aesthetic and fashion preferred consumer products.

PROCESSING
- Removal of hair and flesh without removal of pigmentation substances, so as to retain the natural colouring pattern.
- Utilizing the natural fat and sweat gland build up to provide thermostatic function.
- Processing through methodologies that can be integrated to save on cost, water etc. Methodologies to ensure zero build-up of neutral salts, enhanced atom economy and energy efficiency.
- Finishing processes to consist of transparent coating to ensure coverage of post-mortem defects, while highlighting natural pre-mortem blemishes.
- Leather finishing systems to be made more intelligent to incorporate elements of consumer desire, device integration etc.
- Zero waste (liquid, gas, solid) processes to become a norm.
- On line process monitoring systems, non-destructive testing methods, test methods for banned / sensitive chemicals without the need for derivatization, sensors for odour, harmful substance release in tanneries and ETPs.
- Though industry would move into economy of scope model, modifications to processing methods leading to reduction in process time from raw to finish to less than a day from current 7 days is needed.

RAW MATERIAL
- A significant amount of research will have to go in areas such as:
  - Ensuring skin quality, defectless surfaces (especially from diseases), enhancing substance.
  - Biological changes to the skin matrix to delay putrefaction processes by several hours/days.
  - Management of fibre structure, orientation etc. so as to ensure better utility value.
  - Stem cell research to create skin like fabric ex vivo, which ensures compliance to all above as well as to issues of ethics in animal slaughter etc.

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Technology has played a decisive role in enhancing the global competitiveness of industry and to improve the life cycle of processes and products in the chemical value chain. This section highlights the past and current technological trends in three important segments of chemical industry viz., basic, specialty and knowledge intensives and the technological outlook for 2035 considering the likely growth drivers and inhibitors with reference to infrastructure, human capacity building and consumer expectations.
The chemical industry is a major provider of basic building blocks for general consumer, healthcare, construction, textiles, food, defence and other vital sectors of national economies. \(^1\) Global demand growth for the chemical industry is better than the annual GDP growth in several countries including China and India. Technological advances will provide the main driving force to transform the manufacturing processes in three major segments viz., basic, specialty and knowledge intensives of the chemical industry for better environmental and consumer acceptability. The fastest commercial growth areas lie in specialty and knowledge intensive chemicals.

Indian Chemical industry plays a critical role in boosting the manufacturing sector. It contributes approximately 15% to the overall GDP of manufacturing sector. The chemical manufacturing technologies in 2035 will be driven by environment, energy and new consumer demands. The inherent strengths of chemical, bio and nanotechnologies will be leveraged to meet their future manufacturing challenges, through better operation scales, process intensification use of alternative energy/ feedstock.

History shows that the technology has played a decisive role in various subsectors of chemical industry worldwide as well as in India to enhance its global competitiveness and to improve the life cycle of its processes and products in the overall value chain. \(^2\) This report highlights the current and emerging technological trends in basic, specialty and knowledge intensive chemical areas and the technological outlook for 2035 considering the likely growth drivers and inhibitors with reference to infrastructure, human resource capacity building and consumer expectation.

**INDIAN AND GLOBAL SCENARIO**

Indian Scenario: Indian Chemical industry turnover is expected to reach USD 250 billion by 2035 from the 2009 level of USD 64 billion. The share of knowledge intensive chemical sector will increase to 40% level, almost on par with basic chemical sector. The chemical production will reach 260 MMTPA by 2035 with an overall growth of 75-80% during 2010-20. In terms of chemical exports and imports, the Indian chemical industry will be export oriented with an overall growth lead provided by the specialty and knowledge intensive chemical sectors. The R&D expenditure is expected to touch Rs 60,000 crores per annum by 2035 from both public and private sectors. The basic chemical sector is expected to maintain an annual average growth of 5-6% during 2020-2035. The share of Indian chemical exports is likely to reach 50% of their production. Factors like enhanced per capita chemical consumption, higher export competitiveness, more focused growth of specialty and knowledge intensive chemicals and employment of state of art manufacturing technologies will provide the necessary positive push. India will be employing an additional 10 million skilled workers in chemical manufacturing sector by
The Indian chemical sector will invest an additional USD 125 billion by 2020 and USD 150 billion during 2020-35. It will reach 3% of global chemical turnover as compared to around 2% registered now.

Considering the past and current growth levels achieved by the Indian chemical industry, an attempt is made to project its future growth (optimistic) up to 2035 with reference year as 2009. Table 1 provides the details.

**Indian chemical industry will witness and experience following major events during 2020-35:**

- Though naphtha will continue to be one of the important feedstocks for petrochemicals, efforts to integrate with cellulose-based industry will be intensified. The green branding of products and processes will be a major driving force for gaining enhanced global market share and for new technology applications in Indian chemical manufacture. The use of low carbon energy will gain priority in energy intensive segments of chemical industry viz., petrochemicals, fertilizers and inorganic / organic chemicals. It is expected that by 2035 nearly 20% of the fuels in these sectors will be low carbon energy based.
- Demographic advantage to India in terms of growing productive population in 25-35 years age group will enable Indian chemical industry to employ significant number of knowledge workers in chemical manufacturing plants to produce much more sophisticated chemical products to the global markets. Indian chemical manufacturers will use a variety of biomass-based resources from non-edible sources like straw, plant products and those containing polymers derived from plant cell walls. The enabling biological sciences viz., genomics, proteomics, synthetic biology, metabolic engineering, fermentation processes and high efficiency downstream separations will be of great value to make equivalent chemical products in a sustainable fashion.
- The three Es viz., environment, energy and efficient manufacturing processes are likely to make deeper impact on Indian chemical industry during 2020-35. The impact of international treaties on Indian chemical industry will be much more deeper. They include Montreal Protocol, CWC-1997, the Stockholm Convention on Persistent Organic Chemicals (2004), Kyoto Protocol on greenhouse gases and Registration, Evaluation and Authorization of Chemicals (REACH) policy of EU. Their perceived effects are more stringent process / products safety regulations, shift from end to middle of the pipe strategy for evolving clean technologies, use of catalysis and allied tools for process intensification, advanced process control and optimization and recycle or utilization of wastes. Chemicals with unfavourable environmental footprints particularly with reference to ozone depletion and greenhouse gas effects will be phased out. Typical examples are CFCs and HCFCs.

**Global scenario:** The global economy is expected to grow by 4+% per annum till 2035. It will be driven mainly by the rise of Asian and South American countries and the growing clout of middle class in...
The global chemical industry is divided into basic, specialty and knowledge intensive chemical segments based on their process and product differentiation, physico-chemical characteristics, user market structures, management practices and technological factors. Their total turnover may cross USD 5 trillion by 2020 and USD 8 trillion by 2035. The share of Asia Pacific countries in global chemical production will cross 60% by 2020. A 38% increase in fossil fuel energy demand is expected from global chemical industry by 2035 in spite of energy conservation and lower carbon and renewable energy usage by it. The USA will continue to be the largest chemical consuming market in the world with the share of European countries declining and Asia Pacific countries increasing. The global economy is expected to grow much faster from 2014 onwards. Non-conventional feedstock and energy resources will create significant technological and economic opportunities for chemical industry growth. Demand-pulls are anticipated in Asia Pacific countries for polystyrene, nylon, polycarbonates, polyester fibres and polyethylene terephthalate. Benzene production is likely to diminish with crackers shifting to lighter feedstock. Lower priced methane is likely to be available from shale gas. The main focus of the global chemical industry in the coming years will be to create minimum environmental footprints and maximum resource utilization efficiency.

Growth impacting factors: The future population growth, ageing and urbanization trends, resource shortages, shifting economic power to Asia Pacific countries and climate change will reshape the chemical industry in the world. By 2035, the chemical industry will deliver a new mix of basic chemicals from more renewable resources than at present and higher value added specialties and knowledge intensives with much less adverse health and environmental impact. Structurally, the chemical industry of 2035 is expected to be a much tighter integrated network of large, medium and small-scale plants with flexibility to use a wider range of feedstock in a more inclusive innovation ecosystem. The global regulations based on Montreal Protocol for ozone depletion, Kyoto protocol for greenhouse gas reduction, chemical weapons convention for regulation of dual purpose chemicals and REACH stipulations of European Union will shape the future product technologies of the chemical industry.

The basic chemical sector will witness increased per capita consumption of petrochemicals, fertilizers, polymers and plastics in China, India and Brazil by 2035.

Growth inhibiting factors: Globally, 85% of chloroalkali and knowledge intensive chemicals particularly, pharmaceuticals and pesticides are being manufactured from chlorine containing precursors. Chlorine tree is highly expanded and based on nearly 42 MMTPA of chlorine produced in the world for generating end products and intermediates containing chlorine as well as no chlorine. Polyurethanes, polycarbonates and epoxy resins belong to the latter category. The phase out of several chlorine compounds will gather momentum in coming years due to international restrictions on their use. CFCs and organochloro pesticides (including DDT) have already been phased out in several countries. Following are on their way out: a) chlorinated and brominated flame-retardants; b) chlorinated solvents (methyl chloride, carbon tetra chloride, trichloroethane, perchloro ethylene and trichloro ethylene); c) polychlorinated biphenyls; d) chlorine containing dry-cleaning fluids; and e) wood preservatives (penta chloro phenol).

Though international efforts are being made to develop alternatives to PVC, its phase out in major developing countries will take much longer duration. Their phase out strategy would be based on case-by-case examination of environmental impact, restricting their usage and seeking alternatives. By 2035, the chlorine tree will become much leaner on account of deletions of several chlorine compounds.

More pronounced role of biotechnology: A wider range of bio-catalytic processes will be employed for chemical manufacture employing a variety of enzymes. The characterization of their biodiversity is still a challenge. Extreme environment surviving biological precursors are expected to
Manufacturing technologies have played a vital role in the growth of Indian chemical industry. It has successfully adopted globally competitive processes with advanced control and automation for a wide range of market relevant products. It has made consistent efforts to improve process and product efficiencies by tapering down material and energy consumptions and by curtailing process steps. It has made very effective use of chemistry and enabling disciplines like catalysis, biotechnology and material science and process design/ modeling. Chemical manufacture is highly research intensive with R&D becoming the single most driver of process / product innovations.

**BASIC CHEMICALS**

The Indian basic chemical sector will witness environment, energy and eco-friendly resource driven changes in the coming years. Process intensification will be one of the major trends in technology development. The major chemical subsectors that will employ biotechnologies on a wider scale are pharmaceuticals, cosmetics, detergents, food additives, surface coatings, agrochemicals, polymers/fibres and organics. The future prospects for biotechnology application in chemical sector will lead to 40% reduction in cost, 80% reduction in the use of non-renewable resources, 50% reduction in volatile organics and 65% reduction in water pollution. Their commercial potential will be gradually enhanced as the integrated bio-refinery concept gains wider acceptance. The implementation of lingo-cellulosic biorefinery concept will facilitate the production of platform chemicals viz., lower alcohols, diols, polyols and dicarboxylic acids through fermentation and hydrogenation processes. The production of aromatics through biocatalytic processes is still a challenge. One of the options is to produce butadiene from bioethanol and later convert it into aromatics. Ethylene and propylene production from bioethanol still requires a chemical transformation step.

The polymers / plastics most of which are currently synthesized from petrochemical feedstocks will face more environmental concerns due to low biodegradability, high GHG emissions and disposal problems. Their global demand may touch 0.5 billion tonnes by 2035 with LDPE, HDPE, PP, PVC and PET constituting two thirds of their total market. The production of bioplastics from renewable sources (starch, sugar and cellulose) will pick up by 2020 to reach an annual production level of 3.5 million tonnes. Their current consumption is around 1 million tonnes, which is 0.4% of global plastics consumption. In recent years, bioplastics are being favoured in consumer electronics, automotive interiors, housing and industrial components.
the major tools to be employed for enhancing the efficiency and selectivity of concerned chemical reactions. The major unit processes involved in petrochemical synthesis viz., steam, catalytic fluid and hydro cracking, hydro-treating, coking, alklyation, oxidation, dehydrogenation, steam and catalytic reforming, isomerization, aromatization, cyclization, dimerization and polymerization. The major unit operations include distillation, solvent extraction and stripping. There is a complex linkage between upstream and downstream products. The ethylene and propylene have the highest weighted growth. Inspite of the tremendous advances made in the petrochemical synthesis, potential still exists for improving product yield and quality, better gas/vapour – solid/liquid separations, more innovative regeneration and recycle options and energy/material optimization. The ability of petrochemical manufacturing companies to respond quickly to constantly growing environmental and market demands determines their sustainability in the coming decades. Some of the emerging petrochemical are based on CO₂ as the feedstock for hydrogenation, dehydrogenation reforming Fischer Tropsch type synthesis and allied unit processes. Some of them are biotechnology driven.

Future developments in biorefining in India with multiple biomass-based feedstocks will provide a wider product base from renewable resources for the Indian petrochemical sector. Long term prospects exist in India for the natural gas substitution with synthetic natural gas obtained from biomass gasification, ethylene with bio ethylene, traditional plastics with bio substitutes viz., PET with PLA (poly lactic acid), HDPE with poly hydroxyl alkanates (PHA) and Nylon with polytrimethylene oxide.

TABLE 2: Emerging petrochemical technologies

<table>
<thead>
<tr>
<th>Process</th>
<th>Reactants/Product</th>
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<tbody>
<tr>
<td>Oxidative Dehydrogenation of alkanes</td>
<td>Ethylene, Propylene</td>
</tr>
<tr>
<td>Direct catalytic Hydrogenation of CO₂</td>
<td>Methane</td>
</tr>
<tr>
<td>Dry reforming of Hydrocarbons employing CO₂</td>
<td>Synthesis gas</td>
</tr>
<tr>
<td>Tri-reforming of Methane (Reforming + Partial Oxidation)</td>
<td>Synthesis gas</td>
</tr>
<tr>
<td>Direct synthesis of Dimethyl Carbonates</td>
<td>Methanol, CO₂ as reactants</td>
</tr>
<tr>
<td>Direct synthesis of polycarbonates (Copolymerization)</td>
<td>Epoxides and CO₂ as reactants</td>
</tr>
<tr>
<td>CO₂ based gas to liquid (CO₂ – GTL) technology</td>
<td>Gasoline, diesel, jet fuel</td>
</tr>
<tr>
<td>Biomass Gasification and Subsequent Cracking</td>
<td>Methanol, DMF, Ethylene, Propylene</td>
</tr>
<tr>
<td>Biomass Pyrolysis followed by Bioreforming (Biocatalysis)</td>
<td>Mixed Xylene, Naphthalenes</td>
</tr>
<tr>
<td>Bioplastics from starch, sugar and cellulose</td>
<td>Olefins etc., LDPE, HDPE, PVC replacements</td>
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</table>
terephthalate (PTI). Bio-polymers can also be produced from starch and cellulose by fermentation followed by conventional polymerization or through the microbial technology to synthesize biopolymers directly. Typical examples are polyols from xylose and arabinose, conversion of glucose with 1,3-propane (GT) diol by genetically modified microorganism and polymerization to 3GT and succinic acid from sugars.

**Fertilizer manufacture:** The fertilizer manufacture represents one of the most energy intensive operations. The major unit processes include catalytic oxidation and reforming, methanolation and acid neutralizations. The unit operations cover absorption, distillation, evaporation, solvent extraction, crystallization and drying. Mechanical operations like size reduction / enlargement, particle segregation and bagging are also involved. Future Indian efforts will focus on improving the efficiency of their energy utilization through appropriate process technology interventions and modernization of its utility systems. The future Indian fertilizer applications may be effected through controlled release solid formulations. They unlock a new realm of opportunities for minimizing fertilizer losses. Long chain urea formaldehydes, coarse isobutylidene diurea and specific polymer coated formulations are likely to be employed for new controlled release systems. The energy efficiency revamp of Indian fertilizer plants installed during 1970-90 will receive priority to make them more cost competitive. The Indian plants installed after 1990 have better standards in energy consumption. With respect to new product compositions, substantial changes are not likely to emerge before 2035. However, modified products like higher phosphates containing DAP/MAP, granular urea and ammonium nitrate that are harder than prills are likely to find commercial acceptance. Urea ammonium nitrate in liquid form is likely to be favoured in the future for drip-irrigated crops.

At global level, ammonia synthesis technology has undergone evolutionary changes resulting in downward energy consumption from 20 to less than 7 g cal/tonne. Ammonia is equally important for petrochemical and fertilizer sectors and it accounts for more than 20% of the total energy employed. The Indian ammonia plants are designed to produce up to 3000 TPD employing steam reforming of natural gas. Partial oxidation of heavy fuel or residual oils is an alternative option. The steam reforming based ammonia process consists of desulphurization, primary and secondary reforming, shift conversion, CO₂ removal by reactive absorption, methanization to remove CO and ammonia synthesis. In India, major technological changes in this sector are likely to occur in isobaric manufacture with super active catalysts, significant reduction in recycle gases through the employment of ultra high efficiency absorption systems and more efficient intra-reactor ammonia separation. Increased concerns on the contribution of green house gases to global warming will re-ignite the prospects for replacement of steam by CO₂ as the reforming agent. The process is referred to as dry reforming. It is a highly endothermic reaction to be carried out at high temperature and lower pressure employing a Cu/Ni/MgO/ZrO₂ catalyst to achieve maximum conversion. Coke deposition on catalysts is another major issue, which requires new catalysts with limited carbon formation and avoiding any major structural changes at elevated temperatures.

The currently employed phosphatic fertilizer product mix in India is found to be most cost effective at farm level. More than 70% of P₂O₅ is derived from wet phosphoric acid. Though phosphatic fertilizer production technologies are simple, they have been encountering increasing level of environmental concerns. The conventional tank reactor used in phosphatic fertilizer plants may be replaced with a pipe reactor, which can be operated at higher phosphoric acid concentration, and its outlet can be directly inserted into a granulator. The increase in concentration of melt in the reactor will lead to drying cost reduction by 70-80%. There are likely to be some changes in the product mix of phosphatic fertilizers. They include nitrophosphates and their mixtures; compound NPK products and triple super phosphate. Urea synthesis involves two steps viz., ammonia and CO₂ reaction (fast and exothermic) to carbamate formation and
its dehydration (slow and endothermic) to urea. The reactants are stripped from urea solution and recycled back. The carbamate liquor is pumped back to the synthesis section through a series of loops involving carbamate decomposition at progressively lower pressures or employing a stripping process. Future manufacturing processes for urea production will be based on recycle-stripping operations employing a vertical submerged carbamate condenser; primary and secondary urea reactors and a vertical falling film type stripper. In future, a single train urea plant with 4500 TPD capacity can be operated on a medium pressure recycle without a separate ammonia loop. They are cost effective with minimal high-pressure steam consumption. The use of membrane reactor in urea production will facilitate water removal in situ and the process is reported to have a lower energy demand, significant reduction in ammonia and urea emissions, drastic cut in process cooling water requirement and less toxic wastewater quality.

Global potash fertilizer capacity is projected to grow beyond 60 million tonnes per annum by 2035. The fertilizer grade potassium chloride is extracted from the mined ores with impurities consisting of non-clay and clay minerals. Froth flotation technology is employed for heavy media separations and crystallization operations. Major developments in its processing are anticipated in terms of coarse particle flotation, product screening and final compaction. In India, there is no strong resource base for potash fertilizer manufacture. Current efforts are directed towards its extraction from sea bitterns, the salt concentration and purification. A novel integrated process for the recovery of potassium sulphate (SOP) from sulphate rich sea bitterns has been developed. Kainite type mixed salt is obtained by the fractional crystallization of the bitterns and is converted to schoenite, which is subsequently reacted with muriate of potash for its conversion to SOP. End liquor from Kainite to schoenite conversion is desulphated and supplemented with MgCl₂ from end bittern.

**Chloroalkali manufacture:** The Indian chloroalkali industry manufactures caustic soda, chlorine and soda ash as the backbone constituents with their application in paper, soap, detergents, PVC and healthcare sectors. The inorganic chemical sector produces sulphuric, nitric and hydrochloric acids, carbon black, aluminium fluoride and others. Fuel cells are likely to be introduced in caustic soda and chlorine manufacture to utilize hydrogen for their DC power generation. The phasing out of mercury cells will continue in the next decade. More serious efforts are foreseen in optimization of electrolysers with reference to current consumption. Other options are the use of modern coatings for anodes for enhanced operating life and current densities. In order to delink caustic soda manufacture from chlorine, a membrane cell based electrochemical technology for conversion of sodium carbonate to 35% sodium hydroxide will receive attention. Future electrolysis plants will have more advanced cell controls for short circuit elimination and anode protection. Significant level of revamping of chlorine handling systems including compressors, refrigeration systems and hot gas bypass units is anticipated. A new technology for chlorine manufacture based on oxygen-depolarized cathodes is under development in Germany with substantial potential for energy savings (440-530 kWh per ton of caustic soda). It employs HCl instead of brine to produce chlorine as the only product. Such a technology will be favoured if chlorine manufacture has to be delinked from caustic soda.

Solvay process is widely employed for soda ash manufacture. Ammonical brine is reacted with CO₂ to produce bicarbonate, which is then calcined to produce sodium carbonate. The process requires a large amount of steam. Significant efforts are foreseen for optimizing energy fluxes of the system. The other potential improvements that can be made in solvay process are a) utilization of excess CO₂ from ammonia process for soda ash production and b) better heat and mass transfer in CO₂ absorption and NaHCO₃ precipitation zones.

**Inorganic acids:** The inorganic acids like H₂SO₄, HCl, HNO₃ and HPO₃ play a dominant role in fertilizer and industrial chemical manufacture. Their manufacturing
processes have not undergone much change since their discoveries. However, number of scientific and engineering modifications has been made from time to time to make them more commercially acceptable. The future developments in manufacture of sulfuric acid will be through direct conversion of strong SO2 gases coupled with more efficient waste heat recovery. They will have advanced intelligent controls.

The basic chemistry of the nitric acid process has not changed in the last 100 years, though several process refinements have been introduced since then to make the nitric acid synthesis less energy consuming. The current technology for nitric acid production is by ammonia oxidation in the presence of a metal catalyst. Mono and dual pressure options are employed. The latter was developed to accommodate more stringent environmental pollution control requirements. Single plant capacities up to 1500 TPD could be achieved in a single train configuration. A low temperature process for the combined removal of N2O and NOx efficiently has been reported. Future Indian nitric acid manufacture plants will be built on vertical orientation concept with minimum land, equipment volume and cost.

Carbon black and TiO2: The Indian carbon black industry may face the prospect of replacement with precipitated silica for automotive tyre manufacture. The next generation carbon black technologies are likely to be based on hydro treatment of the feedstock to lower their SOx and NOx content and incorporation of NOx burners in the tail gas furnaces of the pellet drying section.

The global production of TiO2 has crossed 4 million tons mark. There are very few TiO2 producers in the world who employ proprietary chloride and sulphate process technologies. Intense R&D efforts are being made worldwide to develop new pigment grade TiO2 with special optical properties. There are no reported substantive novel pollution prevention and control techniques for either chloride or sulphate process employed for TiO2 manufacture nor an alternative technology to these processes. However, following developments are important for India:

- Pressure oxidation eliminating the absorption and desorption of chlorine in CCl4 prior to recycling in chloride process.
- Continuous digestion, fluid bed calcinations, osmosis of strong and weak acid filtrates from pre and post leach operations, solvent extraction of sulphate metals and hydrometallurgical options to achieve a product with better crystal size distribution in sulphate process.

The future opportunities for silicon carbide (SiC) manufacture in India will be driven by the demand for semiconductor electronic devices and circuits to perform effectively under high temperature, high power and high radiation conditions. This is due to the fact that SiC crystals consist of 50% carbon atoms covalently bonded with 50% silicon atoms with each crystal type having its own distinct set of electrical semiconductor properties.

Organics: Most of the organic chemical reactions take place at moderate temperatures, involving catalytic processes and requiring 3 or 4 process steps. The transition from fossil to biomass based processing is likely to make a reasonable potential refinery platforms.

- **SYNGAS**
  - Methanol, Ethanol, DME, Ft-Diesel, Ethylene
- **BIOGAS**
  - Methane, Bio Fuel
- **C6/C5 SUGAR**
  - Furfural, Xyitol, Isoprene, Glutamic And Levulinic Acids, Sorbitol, Adipic Acid, Lysine, Lactic And Citric Acid, Caprolactum, Cellulose, Hemicellulose, Lignum
- **PLANT BASED OILS**
  - Glycerol, Propylene, Glycol, Epichlorohydrin, 1,3-Propane Dial, 3-Hydroxy Propionaldehyde, Acrylic Acid, Propylene, Bio Diesel
level of impact on the future organic chemical technologies in India. Incidentally, the biorefinery concept will reach a tipping point in the coming years. The important driving forces for its development are high fuel oil prices, consumer preference to greener products, corporate commitment and government policies and support mechanisms. The platform biochemicals are growing substantially during 2012-17. The organic chemical segment will be one of the main beneficiaries of the future developments in this area. The technologies will percolate into the fast developing countries like China, India and Brazil in the next 10 to 15 years.

Indian organic chemical sector will attempt improved value chain integration and environmental sustainability. Catalytic and biochemical process technologies will find favor in downstream product segment. For example, adipic acid synthesis from benzene is likely to be replaced by cyclohexane oxidation with 30% H₂O₂ employing a tungsten catalyst or by employing a biocatalytic method using D-glucose. Similarly, the traditional method of maleic anhydride synthesis from benzene through air oxidation with vanadium pentoxide catalyst will be replaced by greener option of n-butane oxidation employing (VO)₂P₂O₇ catalyst.

### Table 3: Emerging Organic Chemical Technologies

<table>
<thead>
<tr>
<th>Process</th>
<th>Reactants/ Product</th>
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<tbody>
<tr>
<td>Catalytic vapour phase ammoxidation [single step]</td>
<td>Aromatics to Nitriles</td>
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<tr>
<td>Single Pot Heck Reaction</td>
<td>Chlorpyridine and N-Butyl Acrylate</td>
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<td>Asymmetric Epoxidation (sharples or shi)</td>
<td>Trans or Trisubstituted Olefins</td>
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<td>Olefin Metathesis for rearrangement of C=C double bonds</td>
<td>Propane conversion to Ethane and 2 Butene</td>
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<tr>
<td>Suzuki cross coupling reaction</td>
<td>Functionalized Polyolefins and Styrenes</td>
</tr>
<tr>
<td>Organic Carbamates from CO₂</td>
<td>Amine, alkyl Halide and CO₂</td>
</tr>
<tr>
<td>Continuous Hydrogenation of Furfural in Supercritical CO₂</td>
<td>Furfuryl Alcohol</td>
</tr>
<tr>
<td>Liquid Electrolyte and thin film technologies</td>
<td>Dyes for solar cell sensitization</td>
</tr>
<tr>
<td>Nanoecological Dye Technology</td>
<td>100 nm particle size</td>
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<tr>
<td>Polymeric Detergent Systems</td>
<td>For stubborn grease stain removal</td>
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</tbody>
</table>

**POTENTIAL BIOREFINERY PLATFORMS**

- **ALGAE OIL**
  - Bulk Chemicals, Biofuel
- **WET BIOMASS (GRASS, CEREALS)**
  - Carbohydrates, Proteins, Amino Acids, Organic Acids, Hormones, Enzymes
- **LIGNO-CELLULOSIC**
  - Ethanol, Lignin, Chemicals
- **BIOMASS PYROLYSIS**
  - Pyrolysis Oil And Downstream Products
Most of the future organic synthesis will be catalytic processes. Their effectiveness will be enhanced by process intensification for improved mass and heat transfer and reaction efficiencies. The impact of greener solvents will be quite significant on organic chemical segment in terms of phase out of chloroorganic and other environmentally less friendly solvent systems.

**SPECIALTY CHEMICALS**

Indian specialty chemical sector will be more knowledge driven to pursue an accelerated growth path. Currently, the demand is mostly driven by the growth prospects of end use industries. Indian export of specialty chemicals to developed countries is based on its ability to leverage its low cost of production and quality talent pool. Innovation and sustainability will be the major factors for its future competitive performance at global level.

**Product development approach:** The progressive replacement of non-renewable feedstock and energy resources will present real challenges to Indian specialty chemical manufacturers after 2020 while developing alternative products with good market acceptability. Biomass and biotechnology driven products and processes with less energy consumption will be favoured for the manufacture of higher end surfactants, personal care products and fine chemicals. Specialty elastomers and adhesives will switch over to biobased C3-C5 hydrocarbons feedstock. The achievement of a specific optical activity through asymmetric / racemic switching will receive greater attention in case of fine chemicals. Nanotechnology application has good potential in personal care products and food processing sectors. Controlled release and encapsulated delivery systems will be favoured in perfumery and cosmetics manufacture to improve their functional properties and application safety. From environmental considerations, the phase out of highly toxic specialty chemicals and development of more ecocompatible alternatives is foreseen in subsectors like dyes and intermediates, paints and surface coatings and chemical auxiliaries.

**Process development approach:** The future growth drivers will be efficient process routes for producing specialty chemicals to reduce their current environmental burden to contribute to higher investments, lower operating costs and minimal plant inventories. The focus will be on atom efficient synthesis, selectivity and yield maximization, recovery and recycle of unconverted precursors and byproduct utilization. There are bright prospects for the employment of heterogeneous catalysis in reactions, which are currently inefficient. A typical example is the solid acid catalysed aromatic nitrations replacing mixed acid nitrations with cumbersome acid recovery process. More proactive industry-academic engagement is anticipated in supporting green chemistry initiatives. Significant reaction and process engineering inputs are foreseen in development and design of specialty chemical processes, which are currently the sole domain of the synthetic organic and industrial chemists. The study of reaction mechanisms, mass / heat transfer limitations, multiphase mixing, separation engineering and hydrodynamics of process systems will be addressed by the chemical engineers in a much more focused way.

**Dyes and pigments:** This segment has to respond more proactively to the colouring needs of a much wider range of user industries due to the manufacturing capacity shift from Europe and North America to Asia pacific countries. The inorganic pigment market segment represents the largest component in volume terms while dyes and intermediate market accounts for larger value. The future technology thrust will be towards: a) environment friendly natural dyes; b) industry – academic joint initiatives on process intensification; c) innovative product development; d) energy minimization and conservation; e) project engineering for expansions and new ventures. A whole new range of dyes and pigments may enter the Indian market in nonconventional application areas. They include liquid crystal display systems, polarizer and colour filters, optical discs, solar energy (PV) capture, dye sensitized polymers in digital and holographic data storage devices etc. The dye-sensitized solar cells (>10% efficiency) are emerging as one of the cheaper alternatives to silicon solar cells. Future efforts will be to enhance their functional efficiency by employing novel
sensitizers and improved device architecture. In case of pigments, the new areas include plastics and special paints, decoration of natural pearls and transparent metal oxide coatings.

**Adhesives and sealants:** The Indian adhesives and sealant industry is expected to achieve Rs. 5000+ crores turnover by 2017. At present, it is relatively small as compared to its global counterparts. Seven major end uses define Indian adhesives industry viz., construction, packaging, transportation, rigid and non-rigid bonding, consumer products and tapes. The first three sectors drive the domestic market. Neoprene, starch and silicone based adhesives are important for Indian market. Their manufacturing processes consist of mixing and kneading the ingredients into a uniform paste/solution or powder. The Indian made sealants are mainly used in automobile manufacture.

Their growing importance in South Asia and Asia Pacific countries will create new manufacturing base in India for products to suit these new customers. They include silane-terminated products; hot melt formulations, new building blocks for reactive systems and advanced versions of pressure sensitive additives. The future adhesive and sealant formulations will be the enablers of lightweight composites for structural applications. In terms of manufacturing technologies for broad-spectrum adhesives and sealants, increased preference will be for state of art technologies with higher level of automation and process control.

The future regulatory push in India will be to limit the use of solvent based adhesives and sealants particularly based on acrylic, polyurethane, polyvinyl acetate, epoxies, styrenic block, ethylene vinyl acetate, silicones and others. Currently, adhesives and sealants are formulated in India by compounding the
base material with fillers, pigments, stabilizers, plasticizers and other additives. New alternatives will be developed to achieve enhanced bond strength, elongation capacity, durability and environmental acceptability. Natural substances like starch, dextrin, natural rubber and novel proteins will find more favour. Though the consumption of low to medium performance adhesive and sealant formulations is quite sizeable but their future marketability may not be very strong. The demand for hot melt adhesives is expected to grow faster since they are amenable to high speed bonding processes. New products are expected for use in civil and metal construction and aerospace industrial segments in India.

**Personal care products:** The current global market for personal care products is around USD 350 billion with Asia Pacific and Latin American countries providing the emerging markets. The young consumers all over the world are looking for more natural ingredients in shampoos, cosmetics and creams. Accordingly, the future technologies for their preparation will be from natural lipids like soyabeans and others. The emerging technologies are enzyme-catalysed functionalization, biocatalysed lipid modification and algal biomass conversion by thermo or biochemical means. The petrochemical products such as polyethylene glycol and petrolatum are likely to be phased out. The future cleaning products will be based on biocompositions like levulinic ketals, which can be extended by transesterification. 1,3 propane-diol will most likely be made from fermentation of corn sugar for application in cosmetic lotions and creams.

Consumer driven innovation provides the main driving force for development of new and novel personal care products. The customer friendly qualities introduced in personal care products are fortification of body defences, nitrification of skin and beautification of body. They include color cosmetics, shampoos, bath and shower gels, toilet soaps, skin creams, deodorants, baby products, after shave lotions, specialty ingredients and fragrances used in air fresheners, bleaches, detergents, washing powders, fabric softners, anticease products etc. Essential oils and aromatic chemicals are building blocks for fragrances. A range of aroma chemicals like amyl salicylate, eucalyptus, hexyl acetate, phenylol and tetra hydro mycernol are in the market.

Future developments are anticipated in nanoscaled encapsulation for controlled delivery of active constituents to the targeted areas, in designing multifunctional formulations with improved sensory characteristics and in evolving new range of special use cosmetics based on multipersonal care aids.15 Alkylation, hydrolysis, esterification, saponification, ethoxylation, sulphation and steam splitting are important unit processes employed in this sector. Cleaner concepts, better process control and minimization of non-renewable material and energy inputs will be the key factors for technology upgradation.

**Fine chemicals:** Dye intermediates are by far the major customers of fine chemicals. As in other specialty chemicals, Asia Pacific regional demands will dominate the fine chemical market. The key environmental concerns are volatile organic emissions, wastewaters with nondegradable organics / inorganics, spent solvents and nonrecyclable solid wastes. Given the diversity of this sector, a wide range of abatement technologies will be employed in addition to introducing alternative product workup techniques. Recovery / abatement of NOx, HCl, Cl₂, HBr, NH₃, SOX, cyanides and hazardous particulates will receive high priority.

The global linear alkyl benzene (LAB) industry is currently experiencing depressed margins and feedstock shortages. Nearly 98% of LAB production is used for linear alkyl benzene sulphonate (LAS) manufacture. The global demand is projected to grow at 2.7% CAGR until 2020. There is likely to be a shift in consumption pattern of synthetic detergents since liquid detergents are gaining better foothold. Future efforts will be to base them on oleochemicals, fatty alcohols and their ethoxylates, sulphates sand amines. The new oil resources like cuphea, jojoba and other nonedible oils will receive attention, since LAS is considered as environmentally less acceptable. These developments will have major bearing on Indian synthetic detergent manufacture.16
The dirt repellent clothing lines based on nanotechnology will have some impact on Indian synthetic detergent industry by 2025. Better strains of enzymes will be developed as washing aids for synthetic detergents with a wider pH spectrum, stability and quicker action. The Indian synthetic detergent industry will be reinventing its product and process technological strategies mainly to overcome environmental and consumer oriented challenges.

**Lipid based specialities:** Lipid process technologies provide a range of products and intermediates needed for nutrition, health, personal care, specialty chemical sectors. In recent years, transesterification is employed for the preparation of biodiesel from nonedible vegetable oils. Methanol or ethanol is employed as the transesterification agent. The transesterification technology is also employed for the synthesis of fatty acid esters of carbohydrates, which can be used as non-ionic biodegradable surfactants.

**Knowledge intensive chemicals:** The future growth of Indian knowledge intensive chemical sector will be driven by the need for novel and more specific human, animal and plant health care systems. Serious efforts will be made to rationalize their product and process portfolios based on new advances in science and technology. Producing safer and greener ingredients will be the major drivers for future process technologies in this sector.

**Drugs and pharmaceuticals:** More than 2400 Active Pharmaceutical Ingredients (API) from chemical synthesis are being employed in the pharmaceutical industry. They are all small molecules (<550 MW) and more than 90% of them contain a nitrogen atom and an aromatic ring and nearly half of them are chiral in nature. Their synthesis is predominantly modular convergent in nature based on simple construction from precursor fragments.

In spite of impressive product development advances made in this sector, the E-factor viz., the total mass of waste generated per unit mass of a bulk drug still lies in the range of 25 to 100 due to multistep and non-optimal synthesis routes employed with low overall product yields. The following changes are anticipated in Indian pharma process technologies: a) employing more ecocompatible alternative feedstocks / solvent replacements and process re-optimization; b) intensification for cleaner processes employing catalytic biocatalytic / chemo-enzymatics options c) non-reactive and reactive separations d) continuous / microprocessing and e) zero discharge driven waste management. Use of ecofriendly feedstocks for its core manufacturing activities is not expected to take place on a large scale before 2020 due to lack of viable
green alternatives. However, employment of alternative solvents, their quantity optimization and minimization of their losses through reuse/recycle will receive priority. The use of aqueous media, employing one of the reactants as a solvent, direct use of same solvent in subsequent batches etc., are some of the preferred options that will be explored. Future prospects are bright for their large scale deployment of supercritical CO₂, water based systems and ionic liquids.

In recent years, water based reaction media have been employed in pharmaceutical synthesis on a limited scale in Mannich, Michael cycloaddition, asymmetric aldol synthesis and carbon-carbon bond forming reactions. Single pot synthesis in place of 2 or 3 reactions in series is likely to pick up in future for in situ generation of witting intermediates, oxidation and other processes. Use of catalysis for less efficient noncatalytic reactions is likely to be tried on a wider scale in the coming years.

Integration of chemical reactions with mass transfer operations like distillation, adsorption, crystallization and extraction into a single operation (generally referred to as reactive separation processes) provides several attractive options for intensification of bulk drug processes to make them more efficient and clean. Recent successes in reactive extraction of L-phenylalanine and penicillin G provide the necessary incentive for its extension to other bulk drug processes. Transformation of batch to continuous processes will gain more importance from cost reduction, downsizing process facilities, and reduction of energy consumption, better solvent utilization and improved process control considerations. Microreactor technology will also receive a great deal of attention in case of highly hazardous pharmaceutical manufacture.

**Pesticides:** The pesticide manufacturing requires a series of unit processes and operations, executed in batch or semibatch mode to generate desired quality technical product along with release of significant level, of unwanted air, water and solid pollutants. Volume of volatile organic constituents (VOCs) in pesticide synthesis is quite low in comparison with other chemical processes. Future pesticide manufacturing technologies will be more atom efficient, inherently safer, endowed with much less number of process steps, employ minimum solvents or use ecofriendly solvents, use some feedstocks derived from renewable resources and consume minimum energy. As in the case of bulk drug technologies, options like single pot synthesis, reactive separations, catalytic processes, continuous processing and micro reactor application will receive attention in the coming years. Chemically, the solvents employed in pesticide manufacture may be classified as aliphatics covering halogenated hydrocarbons, alcohols, acids, anhydrides, nitriles and aromatics covering halogenated compounds, heterocyclics, aldehydes, ketones, amines and amides. They account for 60-70% of mass utilization and play a dominant part in achieving the desired toxicity profile of a formulated pesticide.

Sustainable pest management depends on the phase-in and phase-out strategies adopted for various categories of pesticides based on their environmental performance. Such developments provide necessary directions to the future growth of Indian pesticide industry.

**Bioproduct manufacture:** Bioproducts manufacture, such as carbohydrates, fat derivatives, steroids, peptides, amino acids, secondary alcohols, nucleotides and chiral compounds need highly efficient process technologies. The enzymes used for their synthesis can be oxidizing or reducing cells, oxido-reductases, transferases, hydrolases, lyases, isomerases and others. The unit processes like acylation, hydrolysis, reduction, reductive amination, oxidation and other regioselective reactions will see more biotechnology applications. Automated batch, semibatch, fedbatch and continuous (plugflow or stirred tank) reactors are employed. The current advances in enzyme immobilization can be extended to cell and tissue components for use as biocatalysts for converting electrochemically unreactive compounds into new range of bioproducts. More efforts are anticipated in the future to employ newer varieties of immobilized enzymes for developing novel drug delivery systems, tumour location analysers and biosensors. Bioresource engineering will
grow faster to explore new biomass sources, to treat more complex biological wastes and to analyse the aerobic and anaerobic digestion options, microbial growth processes and enzymatic catalysis.\textsuperscript{21}

Fermentation will continue to be the major process route in India for the synthesis of antibiotics and other biomolecules. However, the use of new knowledge in molecular and genetic biology will enable its application in the synthesis of newer types of biomolecules including new pest control agents based on genetic modification.\textsuperscript{22} They will enable higher level of product differentiation. For example, newer varieties of therapeutic proteins viz., native, recombinant and fusion types and a wider range of peptides and antibody products will be manufactured in India through microbial fermentation. They will be recovered from the fermentation broths or intracellular; periplasmic, soluble or inclusion type of biomass. The downstream purification operations have to be more robust and scalable.

At present, recombinant DNA technology is employed on a laboratory scale to identify, map and sequence a variety of genes and determine their function. rDNA probes are now being extensively used for analysing gene expression within individual cells and tissues of whole organisms.\textsuperscript{23} There are bright prospects for the Indian manufacture of recombinant human insulin from non-animal sources, human growth hormones, blood clotting proteins from non blood sources and hepatitis B vaccine from yeast cells and HIV diagnosis agents obtained from molecular cloning. Even though the probiotic concept has been around for more than a century, its application in Indian pharmaceutical and bio-products has been somewhat limited. The recent developments in their therapeutic applications have brightened the prospects for developing new range of probiotic products. The nutraceutical field will also be enriched with the modern probiotic manufacturing technologies. Probiotic health supplements based on super high quality strains will receive greater attention in India in the coming years.\textsuperscript{24}

## 3.0  
TECHNOLOGIES FOR 2035

S&T RELATED ISSUES FOR CHEMICAL MANUFACTURE IN 2035

New technology and control packages: An attempt is made to examine the current manufacturing technologies in the Indian chemical sector to identify a) knowledge gaps which need to be attended to by the research and academic institutions, b) productivity deficiencies to be taken care by the industry and c) policy / regulatory initiatives to be taken care by the concerned authorities.

By 2035, the Indian Chemical manufacture will undergo major structural and operational changes under the direct and indirect influence of the national and international regulations. More emphasis will be placed on adopting near zero emission manufacturing concepts involving cleaner process options to minimize air, water and solid waste discharges.

Environmentally more robust technologies are likely to be adopted during chemical manufacture.
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<thead>
<tr>
<th>TECHNOLOGIES</th>
<th>PROBABLE IMPLEMENTATION TARGETS</th>
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<tbody>
<tr>
<td><strong>Vertical orientation concept in Nitric acid plants</strong> for process intensification and improved catalytic basket design</td>
<td>Short Term</td>
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<tr>
<td>Nanotechnology in personal care products</td>
<td>Short Term</td>
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<tr>
<td>Higher mass intensity process routes for producing specialty chemicals</td>
<td>✔️</td>
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<td>Environment friendly natural dyes</td>
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<td>Pigment technologies for transparent metal oxide coatings</td>
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<td>Adhesives and sealants as enablers for light weight composites for structural industry</td>
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<td>Natural lipids (soyabeans and others) for manufacture of personal care products such as shampoo, cosmetics and creams</td>
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<td>Microreactor technology for hazardous pharmaceutical processes</td>
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<td>Recombinant human insulin from non-animal resources &amp; hepatitis - B vaccine from yeast cells</td>
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<td>Probiotic manufacturing technologies for Nutraceuticals</td>
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<td>Production of Biobased polymers (Bio plastics) from renewable sources- starch and cellulose</td>
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<td>Substitution of fossil fuel feedstocks with bioderived ones in petrochemical sector</td>
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<td>Usage of ultra high efficiency systems for ammonia reactor engineering</td>
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<tr>
<td>TECHNOLOGIES</td>
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<td>Shift conversion with membrane facilitated reactive separation</td>
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<td>Immobilized enzymes for novel drug delivery systems, tumor location analysers and biosensors</td>
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<td>Application of molecular and genetic biology for synthesis of new pest control molecules</td>
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<td>Intelligent automation and process controls for specialty chemical processes</td>
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<td>Starch, dextrin, natural rubber and novel proteins for adhesives and sealants</td>
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<td>New processes for high performance materials for chemical sector</td>
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<td>Ligno-Cellulosic Biorefinery for production of platform chemicals (lower alcohols, diols, polyols and di carboxylic acids)</td>
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<td>Biologically engineered algae to replace naphtha as feedstock</td>
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<td>Microbial fermentation for therapeutic proteins (native, recombinant and fusion types), peptides and antibody products</td>
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<td>Dry Reforming of Hydrocarbons with CO₂</td>
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<td>Oxidative Dehydrogenation of Alkanes</td>
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<td>CO₂ based gas to liquid conversion</td>
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<tr>
<td>Usage of pipe reactor in Phosphaticfertiliser plants, to be operated in higher phosphoric acid concentration</td>
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<tr>
<td>Recycle-stripping operations in Urea Plants, leading to significant reduction in process installation size, energy consumption, water consumption, toxic waste water etc</td>
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<tr>
<td>More advanced cell controls for anode protection in Eletrolysis plants</td>
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<tr>
<td>Advanced intelligent controls in Sulphuric acid plants</td>
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<tr>
<td>Condensing acid vapours without emission of acid mist, cooling of vapours and spontaneous homogenous nucleation and heterogenous condensation in Sulphuric acid Plants</td>
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4.0 RECOMMENDATIONS AND IMPLEMENTATION STRATEGY

TECHNOLOGY RELATED CHALLENGES FOR 2035

Technology management, consisting of skilling and capacity building, addressing environmental challenges, stakeholder responsibilities, policy and ethical issues, requires in depth analysis prior to adoption of new technologies.

Human resource capacity building: The National Skill Development Corporation (NSDC) of India had brought out the human resource profile of Indian chemical sector including pharmaceuticals but excluding food processing. It shows that less than 6% of skilled personnel are employed in R&D and knowledge intensive activities. The estimated personnel requirement for Indian chemical industry is around 1.9 million by 2022 with demand predominantly from knowledge intensive chemical sector. A perspective study by the Indian National Academy of Engineering (INAE) has broadly examined the specific features of R&D manpower deployment in basic, specialty and knowledge intensive chemical sectors. The R&D manpower in basic chemical sector is to be well equipped in dealing with green processing, alternative feedstock selection, energy minimization, process intensification and biorefining has been stressed. The specialty chemical sector requires qualified personnel with good expertise in product and process development and an understanding of business and market dynamics. The human resource skills for R&D in knowledge intensive chemical sector have to be based on discovery and development abilities since market value creation in this sector is through the exploitation of tacit knowledge.

The increasing complexity of future chemical technologies requires highly skilled personnel with ability to innovate. Special tools are required to evaluate professional competency of such personnel.


The Ozone Depleting Substances (Regulation and Control Rules 2000) related to Montreal Protocol, the Hazardous Waste Management and Handling Rules-2003 of Basel Convention on the Transboundary Movement of Hazardous Wastes and their proposal, the Chemical Weapons Convention (CWC)-1997 on the prohibition of development, production, stockpiling and use of chemicals with weapons potential, the Stockholm Convention on Persistent Organic Pollutants (POPs) – 2004 and the Registration, Evaluation and Authorization of Chemicals (REACH) of EU Countries -2007 are the major international regulations which already have strong footprints on Indian chemical regulations. The Kyoto Protocol on green house gas emission reduction will have greater impact on Indian chemical sector after 2020 to adopt lower carbon emission technologies.

Along the important value chains of chemical manufacturing industry, process intensification and green chemistry
applications have to be made to moderate the adverse environmental impact on process technologies. Replacement of fossil fuel based energy with renewable energy alone may not suffice to correct the energy demand – supply imbalances in the chemical manufacture. The process operations have to be more efficient to reduce the overall energy demand.

Addressing stakeholder related issues:
The concept of community engagement has been widely employed in chemical industry worldwide to minimize the adverse impacts of chemical processing on people’s safety. For effective use of new products and process technologies, the direct and indirect stakeholders play a vital role. The chemical industry is endowed with multiple stakeholders viz., academic / research community, manufacturers, employees and their associations, governmental and non-governmental agencies, regulatory bodies, consumers, market leaders, traders and distributors, exporters / importers and media. Their combined resolve to promote economically and environmentally sustainable chemical products and processes greatly contributes to the long term stability of the chemical industry. The heterogeneity of Indian chemical industry will introduce a high level of complexity in developing the foresight of multiple stakeholders who are also sectorially divided. MSMEs whose number exceeds 1.11 lakh units in the country, and operating in organised and unorganised sectors in 20 states, pose the maximum challenge in introducing technology interventions. They employ more than 600,000 people of various levels of skills.

The future directions for the stakeholders can be evolved through a multilevel interaction and sensitization process involving various segments of stakeholders. The process is quite complex, labourious and time consuming but is extremely important for promoting innovation, global market competitiveness and technology driven growth of Indian chemical industry. Development of shared vision between manufacturers, their employees, customers and regulators to identify technological priorities for achieving medium and long term chemical product and process sustainability.

Sensitization of the stakeholders of Indian chemical sector on technology development needs to be pursued periodically for long term sustainability. The stakeholders of chemical industry from manufacturing domain favour long-term stability with reference to environment and economic factors. They would like to see minimum impact of global uncertainties on Indian chemical manufacture. Their main concern has been the adverse economic impact of global environmental regulations like REACH on Indian chemical manufacture. The concerns of government, academic and R&D agencies pertain to poor industry linkages, lack of adequate financial resources for process scale up and commercialization and drop in registration of patents being filed in Indian chemical sector as compared to overseas registration. The concern is also on the slow pace of technology upgradation being undertaken in the basic and specialty chemical sectors with reference to environmentally cleaner processing. The stakeholders from Indian and global chemical markets are concerned with the slow response of Indian chemical sector to the consumer preferences in Asia Pacific countries as compared to those form European and American continents.

Policy Changes and Ethical Issues
Policy changes: The need to earn the public confidence on chemical product and process safety and increased use of renewable resources has to be the principal theme of chemical management policies in India. They have to be based on the concept that safety is a shared responsibility between government, industry, the value chain and the consumers as well as the users of the technologies. Various developed countries and geographical regions are evolving new policies for better chemical management for quick adoption of improved technologies. Such policies have to be evolved in India in the coming decade to minimize technological, economic and societal risks of chemicals and processes. They include:

a) Manufacturing companies to generate more chemical and process safety information to enable consumers to appreciate safe use determinations
b) Risk consideration to reflect on prioritizing chemicals for safe use
c) Separate consideration to be given for population vulnerable to chemical exposure
d) Encouraging technological innovations and generation of globally competitive technologies by driving innovation towards greener and more sustainable product or process options
e) Fiscal incentives for the development and deployment of greener and energy / material efficient chemical products and processes
f) Expedited regulatory process to incentivize adoption of renewable feedstock, cleaner production and sustainable product options
g) Strong support to research and development by universities, R&D institutes, industry and other stakeholders
h) Special support to training and education of chemical industry scientists, engineers and technicians in renewable and greener technological options

The future Indian policy framework for chemical manufacture will not only address the human safety concerns adequately but also encourage the continued flow of new useful chemicals from time to time.

**Ethical issues:** Ethics in chemical manufacture forms a subset of transparent chemical business practices. It is meant to ensure that the chemical manufacturing activities are not damaging to the consumer or the society in general. Ethical problems also arise out of new manufacturing technologies that may contribute to unknown effects on human health, safety and environment. The cost efficiency of many technologies can sometimes be achieved at the cost of quality and product safety. The ethical dilemmas occur in manufacturing processes caused by the involvement of unsuitable manpower; improper working conditions and fast depleting resources. In case of specialty and knowledge intensive chemicals, ethical issues mainly arise in case of user’s right for information and product developer’s intention of non disclosure. As chemical manufacture becomes more and more regulated from quality and safety considerations, it has to rely more heavily on a code of ethics in its everyday practice. There may not be a common global standard on the code of ethics for chemical manufacturers, but every organization has to evolve a set of guidelines on ethics.

**Evolving an action plan**

Though it is extremely difficult to evolve a precise action plan for taking the Indian chemical sector to a position of adequate global strength by 2035, the general contours for such a plan need to be evolved with focus on following:

- Industry foresight development on emerging technologies to meet national and global demands
- Establishing appropriate mechanisms to strengthen industry – academic linkages to pursue sponsored research of industrial relevance.
- Motivating R&D institutions to undertake product/process development in emerging areas with focus on greener chemistry and engineering
- Preparing project engineering companies to develop basic and detailed engineering packages for setting up commercial ventures
- Exploring Investment Opportunities in new technology areas for setting up large-scale demonstration and full-fledged commercial ventures.
- Commissioning of new ventures with a strong industry – R&D base
- Developing new expertise in novel product development in knowledge intensive areas
- Human Resource Development in R&D, scale up and commercialization of new chemical processes and products.
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Metal fabrication covers a wide range of activities – from general welding, forming, casting and cutting to highly specialized additive manufacturing concepts and is an important link for industrial competitiveness. Metal fabrication involves both the demand for raw materials and intermediate components, such as financial services, transportation, software and many other services within a national economy. It is an industry concerned with the skills and creativity to manufacture complex, high specialisation products.
Metal fabrication is a value added process that involves the construction of machines and structures from various raw materials. The main function of the metal fabrication industry is to produce component metal parts that will fit in along with other parts, to form larger machinery. In this way, the metal fabrication industry proves to be an essential section of the entire global metal industry as it produces minute spare parts of larger heavy machinery and equipment, which cannot be manufactured simultaneously with the manufacturing of the heavy machines. This sector represents a critical component of the economies of many developing countries including India. Development of this sector will have implications for other areas of national development of non-metallic minerals, construction, information and communication technology, energy, tourism and the distributive trade.

The Indian machine tool industry has come a long way during its 65 years of organized development. India now ranks 16th in world production and 11th in consumption as per the Annual Report (2013-14) of the Indian Machine Tool Manufacturers Association (IMTMA). There has been a negative growth due to the then prevailing manufacturing scenario in the country. It has the capability to manufacture the whole range of machine tools, especially Computer Numerically Controlled (CNC) machines. The industry has good design strength and all its current products are the result of the industry’s own design and development efforts over the last two decades. Nevertheless, the industry suffers from the lack of strong R&D, which is required to propel it to the development of machine tools of the latest technology to compete with the best from abroad. The absence of this R&D has resulted in the industry losing nearly 70% of the domestic market for machine tools to foreign companies.

CURRENT INDIAN AND GLOBAL SCENARIO

Technology development is critical to a country’s efforts in improving productivity, efficiency and competitiveness of its industrial sector. Cost advantages are being replaced by technology related factors such as zero-defect product quality and international certification of firm’s quality assurance systems (e.g., ISO 9000) in determining international competitiveness. Central to maintaining competitiveness is the ability of producers to respond quickly and effectively to the changing demands of the international market.

Technological capabilities can be best described in terms of three levels:

- **Basic level** involves the ability to operate and maintain a new production plant based on imported technology.
- **Intermediate level** consists of the ability to duplicate and adapt the design for an imported plant and technique elsewhere in the country or abroad.
- **Advanced level** involves a capability to undertake new designs and to develop new production systems and components.
There are very few firms close to the international frontier in terms of product design capability and process technology; technological capabilities of most players are extremely limited due to growing technological obsolescence, inferior quality, limited range and high costs. This adversely affects the ability of the organizations to respond to the challenges of increasing international competition from other low-wage countries like China. Most Indian metal fabrication firms appear to be stuck at the basic or intermediate level of technological capabilities. Although Indian metal fabrication industry has mastered standard techniques, it has remained dependent for highly expensive and complicated technologies.

With this report, we set out to predict the model for the metal fabrication industry for the year 2035. Technology and scientific resource availability in current technology status, technology development initiatives and future imperatives have been identified to propel Indian metal fabrication industry to achieve high growth rates.

A decade ago, India and China had almost the same GDP per capita. India’s GDP is only about half of that of China and is growing only at 6% compared to China’s 10%. Currently, India’s manufacturing sector contributes about 16% to the GDP and its share in world manufacturing is 1.8%. This is in stark contrast to China; where manufacturing contributes 34% to GDP and is 13.7% of world manufacturing - up from 2.9% in 1991. India’s growth has been on the back of a booming services sector, which contributes 62.5% of the GDP. These statistics clearly indicate that while manufacturing has not been the engine of growth for the Indian economy, it now needs to grow at a much faster rate. The growth in metal fabrication sector is dependent on the investment climate.

Global Scenario: Technology acquisition has traditionally been viewed as a source of techniques necessary for initiating production and hence was considered as substituting domestic R&D. In the absence of the inflows of new and advanced technologies, however, there has been little incentive, direction and capability to update the existing technologies. Technology continues to be sourced from other nations, but the firm-level technology absorption is low. This is in sharp contrast to firms in Japan and Korea, which absorb sourced technology and improve upon it. High quality human resources and rich stock pool of engineers and scientists is necessary for innovation. The availability of engineers and scientists determines the ability of a nation to develop competitiveness through differentiation. In terms of availability and quality of scientists and engineers (2014-15 data), India scores highly.
INTERPRETING THE VISION STATEMENT

The industry has summarized its goals and objectives for the year 2035 in the preceding vision statement. The vision statement also suggests that metal fabrication will not be seen as an impediment to a smooth manufacturing process. Rather, it will be integrated into product design such that development and fabrication will be a primary contributor to the superiority of Indian products. In order to compete with other technologies, the quality of fabrication must continue to match the significant improvements being made by the competing technologies. Products must approach zero defects, eliminating the need for repairs and re-handling, and ensuring cost-effectiveness. The vision also states that the Indian metal fabrication industry of 2035 will have a world-class workforce. Although a present concern is that today’s industry is not attracting as much talent as it needs to ensure its future viability, several steps can be taken to change this. A cleaner, more automated factory will ensure a healthier and safer working environment.

ROADMAP APPROACH

This report is constructed by interviewing experts from diverse backgrounds such as entrepreneurs, academicians, researchers and industrialists from leading institutes and industries across the globe. Respondents answered questions regarding the way they expect to do business in 2035 in the areas of research and development, technology, supply chain and logistics, and sales and marketing, and how this compares with their current operations. Based on the responses and various brainstorming sessions with experts from various fields and current industry trends, we have drawn a picture of what metal fabrication will look like in another two and half decade time and where companies will need to focus if they are to succeed going forward.
2.0 TRENDS IN TECHNOLOGY DEVELOPMENT

APPLICATIONS
There is wide spectrum of applications in the metal fabrication sector. The major consumers are automotive and general engineering applications. Some of the major applications are listed:

1. Automotive: Passenger cars, commercial vehicles, two wheelers
2. Auto Ancillary: Transmission & steering, engine, suspension & braking, body parts & chassis
3. Communication: Mobile phones, switching equipment, transmission
4. Electrical: Switch gears, cables and wires, switchgears, wires, motors, transformers, UPS and lighting
5. General Engineering: Construction equipment, textile machinery, engines, boilers, turbines, bearings, valves
6. Consumer Durables: Washing machines, air-conditioners, refrigerators, microwave ovens
7. Plastic Components: Home equipment, writing instruments, moulded furniture
8. Packaging: Plastic containers, metal cans, glass bottles, caps and closures
9. Computing: Monitors, cabinets, modems, printers, keyboards
10. Others: Defence, railways, ship building, medical equipment, bath fittings, hardware

MODERN MACHINE TOOLS
The main requirements from modern machine tools are productivity, precision and reliability. All R&D efforts by the most reputed machine tool builders are targeted at achieving substantial improvement in these aspects of machine tools. Several new machine design concepts and functional improvements have been evolved as a result. The developments of machine tools in India must likewise be oriented towards achieving major gains in the above three areas.

DEMAND PROJECTIONS WITH RESPECT TO 2035
The Indian Metal fabrication sector in the upcoming years is estimated to grow at a CAGR of 6, 7.5 and 9% and is expected to generate revenue of 10 Lakh Crores by 2035.

The demand and the expected industry size for major user segments of metal fabrication in 2035 are estimated. This is to emphasize the opportunity available for Indian metal fabricators to seize upon.
Although Indian organizations are served by a network of national laboratories and institutional infrastructure, these institutions generally fall short of quality when compared to those in industrialized countries, putting India at a comparative disadvantage. The role of national laboratories in designing and innovations varies from industry to industry. The main determinants of success of national R&D institutes appear to be the nature and extent of laboratory-industry interaction, the extent of market orientation of products and accessibility. Since most of the R&D effort is limited to specialized institutes, rather than in-house, market orientation is a weak link.

The range of activities of R&D institutes includes education/training (both academic and practical), research and development (academic, practical, product, process and input material related), provision of information services, and provision of services like testing & inspection etc. Although the range of activities undertaken by these institutes is quite wide, resource constraints with respect to budget, staffing and equipment limit their effectiveness in both quantitative and qualitative terms.

Some of them are located in areas away from the industrialized zones like Mumbai, Delhi etc. Apart from R&D institutes, a number of engineering colleges –provide a steady stream of engineering graduates, while the Bureau of Indian Standards (BIS) is responsible for activities related to the development, promulgation and maintenance of industrial and other standards.

The culture of collaborative research involving different institutes has not been promoted in past and the limited resources are not pooled through networking to
develop core technologies in sectors where Indian industry has potential. Another vital link missing is the isolation of universities from R&D. While universities are the major research centres in almost all developed countries, especially Germany, Taiwan and Korea, in India they are isolated from scientific research and advancements. This is largely because government funding of the research institutes does not goad them to seek funding from industry and industry associations through fees and royalties charged for work performed. This results in low commercial orientation.

ANALYSIS OF INDIAN METAL FABRICATION INDUSTRY

An analysis has been carried out in order to understand the industry’s situation, from which a diagnostic report was obtained for decision making in the sector. The factors identified gave rise, according to their degree of development, to positive implications and at the same time issues inhibiting progress. Understanding the dual nature of the factors allows a deeper analysis of the degree of momentum necessary to trigger a positive impact in the sector.

TRENDS

This framework is created to cope up with the following trends

**Accelerated technological Change:** Metal fabrication is a technology-dependent business that can be drastically affected by scientific breakthroughs and innovation. New advancements can present new threats or new opportunities, making the future less predictable. Technological change has a disruptive influence that increases the risk attached to R&D investments, and makes obsolescence or simply falling behind, a constant threat. Metal fabrication firms are pressured to be innovative, and technologically up-to-date with limited capital resources.

Recent years you have witnessed the development of high energy density, life long batteries for transportation. Once this is successful, the demand for metal fabrication will fall drastically, since automobiles will no longer use the conventional engines and gear trains.

**Intensified global competition:** For the Indian metal fabrication industry, global competition refers to more than the competition from foreign firms - it refers to all firms and industries that seek to offer an alternative to metal fabricated components. This includes component manufacturers who employ different methods of metal processing as well as those who use different materials (e.g., plastics). As traditional competitive advantages erode, the industry will experience increasing price pressure and a greater risk of commoditization.

**Increasing customer demand:** The industry must deal with a customer who is more demanding in terms of price and quality and of new functionalities and applications. Increased customer demand puts a premium on both continuous improvement and continuous innovation. Metal Fabricators are pressured to provide components that maintain the traditional benefits of strength, reliability, durability, and at the same time offer new benefits and new functionality.

TECHNOLOGY GAP ANALYSIS

Challenges faced by Indian metal fabrication industry require support from both government and industry. Therefore, to improve overall competitiveness (cost and quality), we have to improve national as well as firm level competitiveness. Listed below are the gaps of Indian metal fabrication industry benchmarked against the global best. This has to be bridged in order to reach global level competitiveness

• Energy intensive operating mechanisms
• Low level of customisation
• Low level of automation
• Capability to manufacture versatile products but inexperienced workforce
• Low technology innovation
• Lack of focus on core competencies and poor process capability
• Poor product design capability
• Low focus in reverse engineering
• Poor product life cycle management
• Low level of flexibility, agility and reusability
• Limitations of inter-operability (systems integration, interface with ERP/ MRP/ production controls systems, and software)
• Lack of recognized universal standards for performance specifications
• Limited use of simulation tools

The Indian Metal fabrication sector in the upcoming years is estimated to grow at a CAGR of 6, 7.5 and 9% and is expected to generate revenue of 10 Lakh Crores by 2035.
## ANALYSIS OF THE METAL FABRICATION INDUSTRY

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>STRENGTHS</th>
<th>WEAKNESS</th>
<th>OPPORTUNITY</th>
<th>THREATS</th>
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<tbody>
<tr>
<td>Raw Material</td>
<td>Current availability of high quality raw materials</td>
<td>Poor supply chain management by local manufacturers</td>
<td>Expansion potential for local raw materials</td>
<td>Increased demand for raw materials in other developing countries (e.g. China) leading to upward pressure on prices and supply shortages</td>
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<td>Strong international supply relationships</td>
<td>Weak procurement networks</td>
<td>Joint purchasing by local manufacturers</td>
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<td></td>
<td>Reduction of duties on imported raw materials</td>
<td>Inconsistency in quality and supply of domestic raw materials</td>
<td>Ease of access to US, European and Far Eastern shipping routes</td>
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<tr>
<td>Production</td>
<td>Largest contributor to GDP of all goods-producing sectors</td>
<td>Insufficient product development knowledge</td>
<td>Limited application of clean technology in production</td>
<td>Uncompetitive energy costs</td>
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<td></td>
<td>World-class enterprises in several manufacturing subsectors and industries</td>
<td>Lack of support services (e.g. maintenance, environmental services etc.)</td>
<td>Limited economies of scale</td>
<td>Emergence of China and other low-cost production centres</td>
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<td></td>
<td>Ability to make high quality products</td>
<td>Out-dated processes, systems and work organization</td>
<td>Available techniques to increase competitiveness through raising productivity</td>
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<td></td>
<td>Numerous small and diverse production facilities allowing for a range of focussed markets and products</td>
<td>Low existing productivity</td>
<td>Available equipment and processes for re-tooling</td>
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<td>Low existing capacity utilization</td>
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<tr>
<td>Marketing</td>
<td>Attractive Brand India appeal</td>
<td>Weak knowledge of external consumers, technology, and marketing trends</td>
<td>Trade liberalization providing enhanced access to export markets</td>
<td>Global economic downturn which may reduce the demand for manufactured exports</td>
</tr>
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<td></td>
<td>Established markets and products</td>
<td>Limited innovation to match evolving market trends</td>
<td>Increasing reach of Internet marketing/e-commerce</td>
<td>Impact of trade liberalization on non-competitive products and industries</td>
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<td>Inadequate levels of matching quality, environmental, health and packaging standards</td>
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<td>Dumping of products that do not meet minimum acceptable safety standards</td>
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<td>DESCRIPTION</td>
<td>STRENGTHS</td>
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<tr>
<td>Finance</td>
<td>Equity investments in manufacturing relatively more attractive</td>
<td>Lack of venture capital and incentives for start-ups and MSMEs</td>
<td>Potential growth from reduced interest rates</td>
<td>Alternative unregulated investment vehicles as diversion of capital from investments in Manufacturing sector</td>
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<td></td>
<td>Lack of low cost capital to fund expansion</td>
<td>Strategic cross-border alliances and partnerships</td>
<td>Potential increases in cost of capital</td>
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<tr>
<td>Human Resource</td>
<td>Large employer of labour</td>
<td>Limited entrepreneurial spirit</td>
<td>Low worker motivation</td>
<td>Brain drain of skilled persons</td>
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<td></td>
<td>Pool of trainable workforce</td>
<td>Limited availability of skills necessary to build viable businesses including:</td>
<td>Manufacturing skills readily transferable to other subsectors</td>
<td>Poor work attitudes</td>
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<td></td>
<td>Innovativeness of people</td>
<td></td>
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<td>Lack of trust and social capital</td>
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<td>Technology</td>
<td>Some plants significantly use modern technologies</td>
<td>Inadequate plant systems and new technologies</td>
<td>Weak product innovation</td>
<td>Intense international adoption of new technologies by foreign competitors</td>
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<td></td>
<td>Use of CAD/CAM tool in all areas of Metal Fabrication</td>
<td>Mismatch of market trends/needs and technical applications</td>
<td>Existing technologies for waste optimization</td>
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<td>Low utilization of Quality Management Systems (QMSs)</td>
<td>Opportunity to transfer technology from foreign investors and suppliers</td>
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<td>Weak linkages to R&amp;D resources (private and academic)</td>
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<tr>
<td>Environment</td>
<td>Availability of some <code>green</code> raw materials</td>
<td>Limited use of environmentally friendly/clean production technologies</td>
<td>Management Systems (EMS)</td>
<td>Impact of international environmental laws as potential barriers to trade</td>
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<td>Lack of use of waste as a resource</td>
<td>Growing demand for environmentally-friendly products</td>
<td>Potential impact of natural and man-made hazards on sector</td>
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<td>Low utilization of Environmental</td>
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Drivers

Economic Drivers: The process of globalization has enabled sourcing capital where it is cheapest, producing where it is most efficient, and selling where it is most profitable. The markets could be for products or for factors of production, such as capital, labour or enterprise. The integration of markets takes place basically due to the removal of restrictions, both in terms of price barriers. Thus, countries have to compete in global goods market mainly in terms of quality and price. Industry is now moving towards a lean manufacturing and automation, propelled largely by concerns of quality, productivity and overall cost. This is perhaps the reason for the increase in manufacturing output without corresponding increase in employment. If India doubles its manufacturing output, employment will not be doubled. It will increase likely by 30 - 40% atmost. India has an advantage in IT and niche engineering sectors, where it has established quality competitiveness. From this base, it could move up to product differentiation and technologically sophisticated product development to convert the challenges posed by globalization into opportunities.

Intellectual Property Rights (IPR): India requires a better institutional set up for protecting IPRs and a greater awareness about the issues involved.

Productivity:

Multi Tasking Machines: In order to reduce set-ups and component handling, machine tools have more functions built into them so that they can handle different machining tasks on one machine. Such machines are highly productive, but require several spindles, tool turrets/tools and workholding features built into one machine. Typical examples are turn-mill machines. Indian machines must be built with similar capabilities for niche applications in petroleum, defense, automotive and aerospace industries.

High speeds: The application of high spindle speeds and traverse/feed rates are very common to achieve high productivity by reducing idle times. While Indian machine tools have recorded some improvement, R&D into machine static and dynamic behavior; vibration and thermal control is required to meet global benchmarks.

Cutting tools and tooling: Indigenous R&D so as to develop cutting tools to achieve high productivity is essential. Machine tool electronics: Indigenous development of high performance axes drivers; motors, drive controllers and CNC that form the core of machine tools, coupled with a strong R&D is essential.

Automation & Mechatronics: An important component of modern machine tools, which needs strengthening through R&D.

Precision:

Thermal control: In machine tools, thermal behavior determines the long-term accuracy. Benchmarking against the best such as use of epoxy-granite structural material for improving thermal resistance, using thermal sensors at critical points to get information leading to ability to compensate thermal deviations, multiple cooling circuits to carry away heat generated, ensuring internet connectivity so as to adopt ‘internet of things’ and technologies like MT-connect for machine-to-machine and machine-to-supervisor controls.

Static and dynamic properties: Obtaining high precision also requires machines to be designed with high static and dynamic properties. Materials such as epoxy-granite to realize high damping of structures, use of sandwich structures with metal foam to damp vibrations, using fibre reinforced composites etc. are to be investigated upon. Active vibration cancel systems to push metal removal rates higher and thus improve accuracy and finish on the component are some of the best practices. Lighter structures for higher acceleration and faster traverse rates without lose of dynamic rigidity and static stiffness is another approach.
Reliability:
Reliability modeling: Using CAD/CAE tools to build machine tools that can deliver 98% uptime, 5000 hrs MTBF and minimum MTTR is a way forward. This requires reliability to be engineered in at the design stage itself. So R&D into the subject is of importance. It should generate a model of the machine and be able to predict failure modes, probabilities, cost etc. using data on the individual elements going into the design. Smart machines: Incorporate sensors for machine tool condition monitoring which triggers suitable response during operation and also when repair/replacement of items is required. Such sensors also permit self-diagnosis and correction and extend autonomous working of machines. Smart machines and controls that “know”, “learn” and “improve” are the machine tools of the future. Being a nascent field, India can enter this R&D field with some advantage.

Technical Drivers: The current roadmap contains the following sections:
- Materials technology
- Manufacturing technology
- Design

For each of the areas listed above, the critical trends and driving forces affecting it, the performance targets given in the beyond 2035, the technical and other barriers preventing the industry from achieving these performance targets, and the research and development activities that the industry has recommended for overcoming the barriers have been provided.

Others:
Machine tool elements: Like electronic systems, the machine tool industry depends entirely on imports for its requirements of aggregates like antifriction bearings, guideways and ballscrews. These are the “mechanical heart” of the machines. The industry needs to develop manufacturing facilities for these components, which calls for intensive R&D.

Measuring systems: All modern machine tools use very accurate rotary and linear measuring devices for position feedback. These are usually based on optical transducer technology such as encoders and linear scales. World-wide, just two or three companies have monopolized this technology. All control manufacturers also buy from these sources. Along with the development of machine tool electronics, the development of such measuring systems should also form part of the R&D program.

ANALYSIS OF TECHNICAL DRIVERS

| MATTERAL TECHNOLOGY | TO GASULATE MATERIAL AND QUALITY INTEGRATION | • EFFECTIVE USE OF MATERIALS • HIGHER VALUE COMPONENTS • NON-DESTRUCTIVE TECHNIQUES | • DEVELOP DIMENSIONALLY STABLE MATERIALS • DEVELOP TOOLS WITH LONGER LIFE • VIRTUAL LIBRARY OF MATERIAL PROPERTY |
| MANUFACTURING TECHNOLOGY | • INCREASE OVERALL PRODUCTIVITY • REDUCE AVERAGE LEAD TIMES • REDUCE ENERGY CONSUMPTION PER UNIT VALUE | • CONTINUOUS IMPROVEMENT IN METAL FABRICATION PROCESSES, PROCESS CONTROL MECHANISMS, MATERIAL FOR TOOLS, AND ENERGY EFFICIENCY | • NEW COST EFFECTIVE TECHNOLOGIES • MODELLING TECHNOLOGY |
| DESIGN | • IMPROVE SPEED AND ACCURACY OF DESIGN AND SIMULATION SOFTWARE | • EFFECTIVE USE OF THE DESIGN AND ANALYSIS TOOLS AVAILABLE TO INCREASE ABILITY TO CONSTRUCT A CONCURRENT DESIGN | • USE OF SOFTWARE’S FOR DESIGN AND SIMULATION OF ALL METAL FABRICATION PROCESS • USE OF SMART TOOLS FOR FAST AND INTUITIVE DESIGN |
Other systems: The development of other systems such as high pressure coolant pumps and filtration systems, balancing systems, smart machines with sensors for monitoring and autonomous operation etc. are also important components of machine tool technology R&D.

Plastics fabrication: With the rising trend in usage of plastic parts in automobiles, compared to the past, plastics fabrication is also an important area to be focussed upon.

**ENABLERS**

Other than the above technical drivers, the rise of additive manufacturing and the mandatory need for green manufacturing initiatives also drives the goals which have to be worked upon till 2035. Also the enablers to achieve the above mentioned technical targets are listed below before going into goals for the future.

- **Lean Manufacturing** – Processes and procedures to remove non-value creating activities and items while reducing waste in operations.
- **Predictive Equipment Failure Methodologies** – Through data mining and analysis, organizations can determine the health of assets through identifying data patterns that tend to be associated with common machine faults. This technology has the ability to eliminate unplanned machine downtime.
- **Visualization tools usage** – Visualization tools have the ability to display high-level machine data in a simple and intuitive format so that problems and under-performing areas can be identified at a glance, thus reducing costs and improving efficiencies.
- **Energy Consumption** – Rising energy prices have created the need to reduce energy consumption and costs. Accordingly, organizations will be looking for improved systems, equipment and processes which will allow for improved energy efficiency and reduced costs. With specific reference to equipment, demand for more energy efficient machinery will cause machine manufacturers to incorporate logic, software, and improved functionality geared toward energy management.
- **Smarter Materials** – Super materials for tools with high thermal conductivity, high corrosion resistance, ductile as well as strong at the same time cost effective to be invented as tools are the back bone of all the metal fabrication processes.
- **Improved chemistry technology** - Enabling manufacturers to carry out simple and complex chemical transformations faster, more efficiently, with fewer processing steps, while offering reduced cost and lower environmental impact.
- **Additive and direct manufacturing processes** - Convert raw materials (such as metal, ceramic or plastic) more directly to finished products without many intermediate steps, using fewer materials and minimizing waste.
- **Light Weighting** - That provides high performance and multi-functionality allowing manufacturers to make products with less materials and lower overall weight without sacrificing performance. Materials can be designed or treated to impart desired properties such as being biodegradable, recyclable or re-engineered after the product’s end-of-life phase.
- **Sophisticated packaging method** - Extend the shelf life of products
- **Green Manufacturing** - The sector must use energy and resources efficiently, and minimize generation of waste. It is estimated that even if every factory, power plant, car and aeroplane is shut down, the average global temperature would still increase by 0.6°C in this century. ‘Green Manufacturing’ or sustainable industrial activity is now the need of the hour and no more an empty slogan.
- **Industries that adopt green practices benefit not only through long-term cost savings, but equally importantly, from brand enhancement with customers, better regulatory traction, greater ability to attract talent and higher investor interest.**
- **Smart/Intelligent Machines** – Machines having self diagnostic, healing and mending capabilities along with capability of informing potential and real failures, greasing etc.

In order to meet the targets set forth in the previous section, the metal fabrication community must be able to hurdle certain barriers, or “Competitive Challenges,” in the following areas: Materials, Manufacturing Integration, Workforce Integrity, and Quality.
<table>
<thead>
<tr>
<th>TECHNOLOGIES FRAME-WORK</th>
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<tbody>
<tr>
<td><strong>IMMEDIATE</strong></td>
</tr>
<tr>
<td>Elimination of distortion and residual stresses in weldment</td>
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<tr>
<td>Robust sensors and controls suitable for hostile environments</td>
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<tr>
<td>Influence of squeeze in die casting</td>
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<tr>
<td>Examine emerging technologies and assess material properties</td>
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<tr>
<td>Advanced die materials with improved thermal conductivity</td>
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<tr>
<td>Eliminate need for lubrication in metal forming processes and develop dry machining process</td>
</tr>
<tr>
<td>Develop direct quenching in controlled cooling environment</td>
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<tr>
<td>Efficient heating and furnace systems</td>
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<tr>
<td>Real time defect sensing equipment</td>
</tr>
<tr>
<td>Tools to address root cause of process unreliability in welding</td>
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<tr>
<td>Tool to evaluate metal forming process parameter effect on end service life</td>
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<tr>
<td>Capability of predicting distortion and understanding effects of residual stresses</td>
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<tr>
<td>Model turbulence in castings for defect reductions</td>
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<tr>
<td>Solid Lubrication technology and alternative for Graphite</td>
</tr>
<tr>
<td>Integration of various machining operations in single head center</td>
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<tr>
<td>Welding filler materials to improve productivity and reduce sound and smoke</td>
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<tr>
<td>Improvements in dissimilar metal joining</td>
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<tr>
<td>Determine alloy requirements (compositions) for thin-wall castings</td>
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<tr>
<td>Develop lighter weight casting alloys</td>
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<tr>
<td><strong>INTERMEDIATE</strong></td>
</tr>
<tr>
<td>Avoid post weld heat treatment</td>
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<tr>
<td>Adaptive welding techniques</td>
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<tr>
<td>Accurate fast and reliable Non-destructive testing to qualify defect free products</td>
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<tr>
<td>Design consideration for semi solid Rheocasting and lost core processes</td>
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<tr>
<td>Advanced post casting processes using robotics and other automatic processes</td>
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<tr>
<td>Heat treatment response alloys for pressure die casting</td>
</tr>
<tr>
<td>Safe and silent forming machines which are maintenance free</td>
</tr>
<tr>
<td>Computer based system to organize and manage tools</td>
</tr>
<tr>
<td>Bi-cycle frames and high-end sports car panels using Hydroforming</td>
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<tr>
<td>New generation of statistical process control for weld applications</td>
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<tr>
<td>Development of model based process control</td>
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<tr>
<td>Develop design-for manufacture tool that is easy to use</td>
</tr>
<tr>
<td>Models that accurately predict weld joint performance</td>
</tr>
<tr>
<td>Develop fast and intuitive mold design tools</td>
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<tr>
<td>Smart molds for continuous monitoring</td>
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<tr>
<td>Advanced concept to promote wetting during welding</td>
</tr>
<tr>
<td>Impact of simulation on shop floor performance</td>
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<tr>
<td>Welding non-metallic for high temperature environments</td>
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<tr>
<td><strong>LONG TERM</strong></td>
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<tr>
<td>Joining at cryogenic temperatures</td>
</tr>
<tr>
<td>Welding techniques without heat affected zone</td>
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<tr>
<td>Rapid die manufacturing technologies</td>
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<tr>
<td>Recyclable and disposable moulds</td>
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<tr>
<td>Automatic set forming machines to save time</td>
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<tr>
<td>Ultrasonic plastic assembly</td>
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<tr>
<td>Welding of micro-plastic parts</td>
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<tr>
<td>Metal cutting operations of miniaturized components having tolerance range in nanometres</td>
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<tr>
<td>High speed additive manufacturing techniques</td>
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<tr>
<td>Develop new materials that have properties comparable to composites</td>
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<tr>
<td>Develop harsh environmentally tolerant sensors to measure 3D stresses</td>
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<tr>
<td>Development of interface between model and design to use in concurrent engineering</td>
</tr>
<tr>
<td>Develop computer design tool to move from a part design to a metal fabrication design</td>
</tr>
<tr>
<td>Develop software to simulate casting processes and casting service under various conditions</td>
</tr>
<tr>
<td>Weldable alloys that eliminate pre &amp; post weld heat treatment</td>
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<tr>
<td>Establish a casting design book that relates properties and types of tests to expected part performance</td>
</tr>
<tr>
<td>IMMEDIATE</td>
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<tr>
<td>--------------------------------------------------------------------------</td>
</tr>
<tr>
<td>• Develop corrosion- and creep-resistant magnesium alloys</td>
</tr>
<tr>
<td>• Forming of composite materials</td>
</tr>
<tr>
<td>• Forming of hard to work materials like Inconel, Niobium, Tantalum and Molybdenum etc.</td>
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<tr>
<td>• Methodologies to deal with composition sensitive materials</td>
</tr>
<tr>
<td>• Filler materials in welding to reduce sound and smoke</td>
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<tr>
<td>• Micro machining of glass</td>
</tr>
<tr>
<td>• Fume free fusion welding</td>
</tr>
<tr>
<td>• Conduct energy audits (water, waste &amp; energy) regularly in all industries</td>
</tr>
<tr>
<td>• Develop emission database for industries to use in educating regulatory bodies</td>
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<tr>
<td>• Mandatory use of foundry sand reclamation process by all foundries across India</td>
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<tr>
<td>• Finishing of Aluminium foams</td>
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<tr>
<td>• Mandatory use of closed loop water system by all manufacturing industries</td>
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TECHNOLOGY VISION 2035

- Advanced and custom-designed materials, developed using improved computational methods and accelerated experimental techniques
- Free form fabrication techniques
- Self-reconfigurable robotics
- Develop noise free metal fabrication processes
- Faster additive manufacturing techniques capable of assembling products by area or by volume rather than by layering materials as is done today
- Biologically inspired nano scale-fabrication processes
- Machine for self-assembly of parts
- Mass production of multifunctional miniature systems
- Advanced and custom-designed materials, developed using improved computational methods and accelerated experimental techniques
4.0 RECOMMENDATIONS

In addition to the technological interventions given earlier, other measures that need attention are as follows.

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Hassan El-Hofy, Advanced Machining Processes: Nontraditional and hybrid machining processes, McGraw Hill, 2005


Food processing is composed of food preservation, manufacturing, nutritional need and socio-economic factors in addition to providing a nation with healthy people. Scope exists to improve the quality attributes of food along with simultaneous decrease in spoilage through innovative technology intervention with a focus on traditional and healthy food.
Food has many roles; the primary purpose being to supply the energy and nutrition required to grow and maintain a healthy human life. After these basic requirements are achieved, food also serves various other purposes, which include social, socio-economic and cultural issues. The overall status is that food is a highly complex subject where science, technology of manufacturing, religion, regional choice and feeling, belief, culture, and knowledge obtained from earlier generations and followed practices are involved and important. The production and consumption of food products also depend on the availability of raw materials in the neighbourhood and the process of converting to an edible form. The area of food processing is also dependent on other allied areas like agricultural practices, dairy industries, and fish, meat and poultry production. Hence, all of these areas have significant roles in the manufacture of processed food and their consumption pattern. It is also worth mentioning here that food processing also includes food preservation, packaging, and appropriate measures for waste disposal.

It is thus desirable that a near future prediction is made now to understand the sector of food processing and preservation. Such an exercise will be useful in attaining the targets for food security and safety. Production of food also links with direct and indirect employment of many people wherein there is a good scope to popularise Indian food in other countries to boost export initiatives and convey the message of healthy lifestyle. The vision document also discusses the expected food requirement, strategies needed for meeting the requirement and other related issues for achieving a nation with healthy people.

This present chapter mentions the status of the current scenario and development of this technology both in India and abroad, and attempts have been made to identify the technological gaps, which as of today are quite considerable in India. The areas, which need to be addressed and focussed, are also indicated in a brief manner. The technology scenarios in 2035 in several fields of human endeavour that will be impacted by food processing and preservation technologies have been incorporated. The document also outlines the approach to develop indigenous know how to make India a global player in this field by 2035.

Being a complex technology depending on many aspects of other areas, it is somewhat difficult to make an intelligent forecast about the market potential for the products manufactured using these technologies. However, an attempt has been made to indicate the trend based on available data, appropriate prediction and optimistic future thought.

**CURRENT INDIAN AND GLOBAL SCENARIO**

The current scenario can be discussed in the context of manufacturing in developed and developing countries. The developed countries are able to provide adequate...
quantity of food, which is safe from the point of hygienic and microbial status. However, these food are not necessarily healthy for consumption as a number of food are fried, and contains high levels of calorie and fat. In addition, the consumption of higher quantity of food than is actually needed by body often ends with overweight and obesity, and associated health problems like cardiovascular diseases (CVD). The existing technologies presently used are the different conventional thermal treatment processes such as baking, frying, canning and drying, low temperature processes like refrigeration and/or freezing, etc while newer preservation/processing technologies that are in the R&D stage include the newer processes like the use of ozone, microwave, radio frequency, high pressure processing, Ohmic heating, infra-red processing, membrane separation, etc. A few attempts are also made to use the irradiation technique as a commercial process of food preservation but the success is limited to a few commodities only in a few countries/places.

In India, the situation is however different. Lack of enough quantity of food for a large population is existing. The FAO report indicates that 15.2% people in India were undernourished during 2012-2014 period, which ideally should be zero by 2035. There are serious efforts to combat the malnutrition problem through government funded nutritional intervention programmes like mid-day meal programme for school children, subsidised raw food materials through public distribution system, etc. However, still the problem of malnutrition is continuing which can be described as a socio-economic problem where low income of people is the real cause.

On the other hand, the problem of diabetes, over-weight and obesity is on the rise for a significant section of people who possess a better financial status. The reasons attributed to these problems are overeating, sedentary life style and continuation of non-healthy food habits.

Concerning the sector of food manufacturing, this industry ranks fifth in the country and employs about 1.6 million people who comprise about 19% of the total industrial labour force; it accounts for 14% of the total industrial output with 5.5% of the GDP. Its turnover is estimated to be at Rs. 1,44,000 crore of which Rs. 1,11,200 crore comes from the unorganised sector. A large proportion of food arising from the unorganised sector may not be necessarily manufactured maintaining the hygienic practices. The growth rate for the Indian processed food is expected to touch a very high level of 13% per annum. The country’s presence in the global food trade of 3% at present can be significantly increased to 10% by the year 2035. There is a good potential in India to build profitable businesses in the sector of food processing. There is a need to have a fresh look at the existing technologies with an orientation towards the implementation of newer technologies that are energy economic and environmental friendly.

FOOD REQUIREMENT FOR INDIA
The vision document emphasises the primary goal of the food security for all citizens of India and availability of adequate quantity of healthy food. Based on the expected population growth by 2035, the requirement of major food commodities like cereals, pulses, oilseeds, fruits, vegetables, meat, fish, and milk have been worked out. It is obvious that the sectors like agriculture, dairy, fishery, poultry and meat preservation and processing industries have to ensure the availability of these essential raw materials and processed food.

Based on the census data (683, 846, 1023 and 1211 millions in the year of 1981, 1991, 2001 and 2011), the projected Indian population in 2035 is 1530 million. It is hoped that the spread in education and better understanding of the societal duties, the increase in population rate may come down. The requirements of major food commodities in 2035 have been arrived based on per capita consumption for the year 2011. As India is already deficient in edible oils and pulses, there exists a serious concern about the increase in production of these items.
Developing a technology backed food-processing industry to provide adequate quantity of safe nutritional food for all the citizens of India along with a marked increase in employment opportunity and export.

VISION FOR 2035

2.0 TRENDS IN TECHNOLOGY DEVELOPMENT

GLOBAL AND DOMESTIC TRENDS
A number of manufacturing practices/technologies is used for developing products of commercial interest. The type of food is shown under different raw materials like (i) cereals, pulses and oilseeds, (ii) fruits, vegetables and spices, (iii) animal products obtained from dairy, meat, poultry and fisheries, and (iv) consumer food (snacks, biscuits, ready-to-eat products and non-alcoholic beverages, etc). The common technologies for all these cases are initial cleaning (to improve the safety of the product), drying (to reduce the moisture content for achieving stability and increasing the shelf life of raw material and product) and packaging (to improve the shelf life of product, avoid contamination and increase consumer acceptance). However, other technologies vary with the raw material and the required final product. It is desirable that all the technologies are upgraded in the coming years with simultaneous improvement in the design of machinery to meet the requirements of the Indian food industries as well as matching with the international standards.

PRESENT AND PREDICTED PRODUCTION OF MAJOR RAW FOOD MATERIALS

<table>
<thead>
<tr>
<th>Material</th>
<th>Present Production (2013-14)</th>
<th>Predicted Production 2035</th>
</tr>
</thead>
<tbody>
<tr>
<td>Food Grains</td>
<td>265.57</td>
<td>394.25</td>
</tr>
<tr>
<td>Vegetables</td>
<td>162.89</td>
<td>336.05</td>
</tr>
<tr>
<td>Milk</td>
<td>132.43</td>
<td>230.45</td>
</tr>
<tr>
<td>Fruits</td>
<td>88.97</td>
<td>165.55</td>
</tr>
<tr>
<td>Oil Crops</td>
<td>53.54</td>
<td>93.54</td>
</tr>
<tr>
<td>Pulses</td>
<td>32.57</td>
<td>65.78</td>
</tr>
<tr>
<td>Fish</td>
<td>15.47</td>
<td>26.67</td>
</tr>
<tr>
<td>Meat</td>
<td>16.07</td>
<td>28.94</td>
</tr>
</tbody>
</table>

Source: Ministry of Agriculture, Govt of India (2013-14); 2035 data – TIFAC estimate
The instant products, which are going to match the future lifestyle of people, are basically to provide convenience to people in terms of saving time of food preparation, avoiding drudgery and for offering nutritional benefits.

TRADITIONAL INDIAN FOOD
The traditional food of India are possibly as old as her civilisation and are an integral part of the culture. Some of these traditional food are also known internationally while a major fraction remains largely unknown to the rest of the world due to lack of propaganda and scientific understanding. The facts and the vision plans on traditional food are as follows:

The limitations of many traditional food are the poor quality due to unhygienic processing, low shelf-life leading to fast quality deterioration, suitability for production only in the household or small scale processing centres, and lack of scientific investigation/data concerning their processing, storage and quality characteristics.

The solution to these limitations is that, there is a need to have a comprehensive research efforts and database concerning processing details, specification and standardisation of the products, shelf life, and mechanisation of the product preparation including packaging. This will help to develop processing lines of selected traditional food, large-scale production, and possibility of export and popularisation of those selected food in other countries.

IMPORTED FOOD
Several unwanted foreign food have entered the Indian market, and they are freely sold throughout the country, and people of younger generation are mostly attracted to those food. Strict quality control measures are required as per the existing law or by amending the laws, and permission is to be provided only after passing the test/specification. There is a need to discourage imported food with high fat and/or sugar content, and if needed, higher tax may be imposed for such items.

NEW LIFE STYLE PRODUCTS
More consumption of convenience food in ready-to-eat/ready-to-prepare/ready-to-cook form, or as convenient mixes, instant food, beverages based on fruits, health drinks (including milk and milk products), water with health benefiting ingredients, ready meals for breakfast/lunch/dinner, ready-to-eat snacks, and specialty ingredients for industries will be matching the fast life style of people in the future.

Instant food can be classified based on the raw materials used such as cereals, pulses, vegetables, instant products of animal origin, beverage products, dairy products and...
The wastage of fruits and vegetables, and grains is the highest in the food sector; a tentative estimate says it is about Rs 44,000 crore per year in India.

miscellaneous instant products. The instant products, which are going to match the future life style of people, are basically to provide convenience to people in terms of saving time of food preparation, avoiding drudgery and for offering nutritional benefits. Several process technologies are going to be employed of which the technologies like instantisation, agglomeration, wet heating and quick drying is to be the common technologies for various products. Among these products, highest scope exists for instant beverage products such as instant tea/coffee/cocoa/instant milk, nutritious (health) drink, coffee creamer, chocolate drink, ready-to-drink fruit juice and easy reconstitution powder, and high density compacted food.

FOOD PACKAGING

Packaging of food provides technological advantages such as protection, easy to carry and transport, resistance to tampering, and special requirements like reducing physical, chemical or biochemical changes. It also contains other legal requirements including price, composition, ingredients used, use of permitted preservatives, net weight, date of manufacture, safe date of use and nutritional facts.

The earlier concept of using rigid containers of glass bottle for food packaging has changed over the years though rigid containers are still in use with several modifications. In addition, the flexible packaging employing different thermoplastic polymers and biopolymers are also employed for convenience, technical suitability and cost reduction. The design of food packages depends on several factors including the reactivity of the material towards environmental factors, moisture sorption behaviour, and attractive features to draw consumer attention, cost of packaging material and the shelf life needed. Active packaging is another concept, which is getting popular at present. Edible films/coatings are manufactured using edible biopolymer ingredients like proteins, polysaccharides and...
lipids. Modified atmosphere packaging of fruits, vegetables and agricultural products, and animal products are the other areas where researches are continuing at present. In addition, newer packaging materials are in the process of development for minimally processed food including microwavable food, high pressure processed food, etc.

The concept of intelligent packaging (IP) is an emerging area of technology which has drawn considerable interest among researchers and consumers. It is an alternative to the ongoing packaging methods as monitoring and maintenance of the safety of products throughout the supply chain are possible in addition to increasing the shelf life of products. The IP system includes indicators (time-temperature indicators, integrity or gas indicators and freshness indicators), bar codes and radio frequency identification tags (RFID) and sensors (biosensors, gas sensors, fluorescence-based oxygen sensors).

Machinery for packaging plays a key role for the manufacture of food products. The selection of packaging machinery depends on the type of food to be packaged apart from its cost and capacity. There is a need to have high capacity packaging machine systems at an affordable price.

Disposal and reuse are the other issues related to food packaging and environmental factors. The use of biodegradable food packaging requires reduced packaging system and appropriate reuse of packaging materials are also the need of the hour. The manufacture of food packaging machinery in low, medium (1000 packets/hour) and high capacities (10000 to 100000 packets/hour) are needed in addition to complete process lines for liquid food like milk, beverages, etc. The blue-sky research areas are the completely biodegradable packaging material for the protection of environment, and the use of nanoparticles in food packaging.

UPCOMING TECHNOLOGIES FOR WASTE UTILISATION
Food preservation and processing generates large quantity of wastes, which are basically organic in nature, and arises from raw materials from the processing of meat/poultry/fishery, dairy and agricultural raw materials. These wastes are in the form of liquid (waste water) and solid wastes. The high moisture content (even upto 95%) allows the materials to degrade faster, which is more severe in the case of a tropical country like India where the environment is seriously affected. The high humidity (70-90%) also promotes wastage in a short time. However, some waste materials may be considered as a by-product (meaning that they often possess some market value) provided appropriate process technologies are employed.

The wastage of fruits and vegetables, and grains is the highest in the food sector; a tentative estimate says it is about Rs 44,000 crore per year in India. The main reasons for this food loss are the lack of cold chains and the inadequate number of cold storage facilities. However, several products of commercial importance can be prepared from the wastes such as candied peel, oil, pectin, alcohol, vinegar; reformed fruit pieces, etc from the waste available from fruit processing industries.

The conventional method of handling waste needs a fresh look for their appropriate disposal or reuse. The technology of anaerobic fermentation, generation of biogas, and energy generation with biogas production is an interesting feature in several places. The wastes coming from fish/meat, fruit and spent grains can be used for the production of food ingredients like dietary fibers, polyphenols, antioxidants, natural colours and protein isolates.

TECHNOLOGY GAP ANALYSIS
There exists a considerable technological gap between India and the developed countries at present. The solution to this problem lies in import and assimilation of technologies wherein development of technologies through R&D efforts within India are also encouraged. The assimilation of these imported technologies to suit products to Indian people also includes detailed assessment of the said technology in addition to understanding the science and subsequent training wherein the industrial applications are of prime importance.
3.0 TECHNOLOGIES FOR 2035

Food processing can be categorised as ongoing conventional food processing and advanced food processing, which will be implemented in the coming years. However, these two systems often overlap, and thus a fresh grouping has been introduced under the headings of existing, near future and future technologies.

EXISTING, NEAR FUTURE AND FUTURE TECHNOLOGIES

**EXISTING TECHNOLOGY**
- Drying
- Size reduction
- Material handling: Solid, liquid and semi-solids like doughs, gels, batters, concentrates, etc
- Extrusion cooking
- Isotope based irradiation for extension of shelf life
- Thermal processing
- Osmotic dehydration
- Extraction processes including filtration, sedimentation, solvent extraction
- Baking
- Frying
- Roasting and toasting
- Flavouring
- Fortification
- Refrigeration and freezing
- Fermentation

**NEAR FUTURE TECHNOLOGY**
Existing technologies (shown in column 1) in addition to the following items:
- Electron beam irradiation for extension of shelf life
- Micronization and encapsulation
- Flavouring and coating
- Instantisation and agglomeration
- Fortification and impregnation practices
- Membrane processing
- Microwave technology
- Ultraviolet and infrared treatments

**FUTURE TECHNOLOGY**
Existing and near future technologies (shown in columns 1 and 2) in addition to the following items:
- Application of radiowave and ultrasonics
- Nanotechnology in food
- High pressure processing
- Ozone processing
- Pulsed electric fields in food
- Ohmic heating
- Automation and robotics

ENERGY EXPENDITURE

The energy sector needs a special mention as it is an integral part of any food processing and preservation method. The energy usage may be conveniently divided into two major sectors like rural and urban sectors. The depleting resources of wood and fossil fuels are going to be a serious concern by another 10 or 15 years, particularly for domestic cooking. In other words, there is going to be a huge shortage of cooking fuel in urban areas and for food preservation/processing industries wherein the answer lies in the use of electrical energy sources obtained from nuclear reactors. The limited petroleum based fuels can be made available only to rural sectors.

It is desirable that the rural community cooking is encouraged to reduce energy expenditure using the concept of centralised kitchen where a person can bring the raw materials and cook there in an energy efficient manner as centralised cooking facility has been proved to be energy economic system particularly for firewood stoves which are still in use in rural sectors and may continue in future in isolated places. Mass cooking in urban areas can also ensure completely mechanised meals at an affordable price. This can also generate adequate number of urban jobs in addition to safe food ensuring healthy practices.

The present vision document does not encourage the unregulated use of low
temperature processing and unnecessary refrigeration/freezing systems as we live in a tropical country. It is rather desirable that dried food/ingredients/ready-to-process food are made available which do not need any low temperature storage or processing. This practice is also an energy saving system.

NEED FOR INNOVATIVE THOUGHTS AND MASS PRODUCTION OF SELECTED FOOD
Innovative concepts are the perquisites to introduce societal benefits for a society having limited purchasing ability. An appropriate strategy is required to adopt the practice of developing cost-effective products for mass feeding and societal requirement and the required research initiatives.

NEUER AREAS ON NUTRITION RESEARCH
The future basic nutrition studies will include micronutrients, nutritional physiology, nutrition and aging, nutrigenomics, lipidomics,

<table>
<thead>
<tr>
<th>TYPE OF FOOD NEEDED</th>
<th>JUSTIFICATION</th>
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<tbody>
<tr>
<td>Convenience food</td>
<td>Rapid urbanisation, more time spent during travel and at workplace, and more people in job require quick or less cooking type of food such as ready-to-eat and ready-to-serve food</td>
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<tr>
<td>Food for elderly people</td>
<td>Specialty food [soft in texture and energy dense] are needed for senior citizen</td>
</tr>
<tr>
<td>Baby Food</td>
<td>Low cost baby food including milk powder are needed</td>
</tr>
<tr>
<td>Children [pre-school and school going]</td>
<td>Protein rich [minimum 15% protein content] food with adequate quantity of energy, minerals and vitamins are needed</td>
</tr>
<tr>
<td>Food for baby born with low weight</td>
<td>Import substitute and cost effective</td>
</tr>
<tr>
<td>Persons under medical treatment</td>
<td>Help to reduce the price and act as an import substitute</td>
</tr>
<tr>
<td>Persons with diabetic problem</td>
<td>The enormous rise in diabetes patients needs specific food to control the sugar level in blood</td>
</tr>
<tr>
<td>Sports persons</td>
<td>There is a lack of food for sports persons who need very high energy intake</td>
</tr>
<tr>
<td>On special duties [like police, duty on border and for armed forces in remote places like hilly terrains, ships, and during travel]</td>
<td>Easy-to-carry homely food, which are also not monotonous</td>
</tr>
<tr>
<td>Working force [like Labourers]</td>
<td>The large number of working forces in urban and rural sectors need high calorie containing food that are safe, low in cost and are tasty</td>
</tr>
<tr>
<td>Lactating mother</td>
<td>This requirement is meant for social cause where the health of both mother and offspring is to be protected</td>
</tr>
<tr>
<td>Low cost nutritious food for all</td>
<td>Required for the people with low income groups</td>
</tr>
</tbody>
</table>
The future of food processing depends on several factors including existing practices, life style requirement and changes, the success of newer technologies and the changing choice of food by people. However, there are possibilities of several interesting and disruptive technologies emerging in future.

**NEW CONCEPT NEEDED/NEW AREAS OF RESEARCH FOR TECHNOLOGIES BASED ON INNOVATIONS**

<table>
<thead>
<tr>
<th>ITEM/ISSUE</th>
<th>JUSTIFICATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bumper crop of vegetables, fruits, tuber crops, etc</td>
<td>For providing appropriate value to the producers and for saving national resources</td>
</tr>
<tr>
<td>Reduction in the wastage of perishable food commodities</td>
<td>Innovative and new process technologies are to be developed thorough R&amp;D efforts</td>
</tr>
<tr>
<td>Traditional food</td>
<td>Understanding the science and developing process technologies to make large scale production possible. The specific traditional food to be focussed are jilebi, gajak, idli, gaja (jibe gaja), dhokla, sohan papri, seasoned roasted dhal mix, etc having increased shelf life</td>
</tr>
<tr>
<td>Novel ingredients and raw materials</td>
<td>For meeting specialty requirements including slow digesting complex carbohydrates, lipids with health benefits, linking food with health protective features, avoidance of health hazards, replacement of medicines with appropriate food items, and substitution of oil/fat with other ingredients</td>
</tr>
<tr>
<td>Macro- and micro-nutrient enriched food</td>
<td>Attractive food with macro- and micro-nutrients for health benefits, and for increasing the shelf life of these nutrients</td>
</tr>
<tr>
<td>Food processing machinery</td>
<td>Energy efficient and cost effective machines are needed which include the processing of traditional food, and common equipment like dryer, grinder, extruder, evaporator, etc with the quality matching the international standards for domestic use and for export purposes. For example: High pressure equipment for food packaging • Equipment for electron beam irradiation • Equipments based on radiowave and ultrasonics • Equipment for volume production of traditional food products</td>
</tr>
<tr>
<td>Carry away meal packets</td>
<td>Convenient meal packets at affordable price and for convenience</td>
</tr>
<tr>
<td>New process technology</td>
<td>Development of new processing systems that is economically viable for application in industries</td>
</tr>
</tbody>
</table>

**JUSTIFICATION**

personalised and molecular nutrition, and health diet and lifestyle. In addition, the new areas like plant-based nutrition healthcare, clinical food technology and food allergies will be the focus of research in coming years.

**DRIVERS**

It is desirable to identify the drivers that help India to become a leading food processing country.

I. Set the objectives clear, and a clear vision concerning the need of the country.

II. Research innovations and scientific understanding which come out of individual, academia and research organisations in the field. It should come out with a number of machines, and technologies and/or products that may be feasible in future.

III. Scale-up where a number of concepts may be screened to find their suitability for large-scale production. The available machineries are to be used whereas the gap can be identified to develop specialised machinery, which is necessary for large-scale production. Understanding of multi disciplinary science based requirements needs coordinated research involving several institutions at this phase.

IV. Standardisation of technology after successful scale-up, ascertaining the quality and acceptance of the product, and commercial viability. This phase needs coordination with industries for large-scale manufacturing, and NGOs/self help groups for cottage and small-scale production wherein the availability of demonstration facilities is mandatory.
V. Release of developed technologies, and consequent manufacturing for consumption in India and abroad.

The drivers are:

a) Mass communication for people
   • The need for healthy food and maintaining good food habits.
   • Avoidance of high sugar or high fat containing food particularly the fried products.
   • Maintenance of hygienic conditions in all food processing operations including domestic sector.

b) Appropriate disposal and reuse of waste

c) Web linked items under awareness programme
   • The school curriculum wherein younger minds (6 to 10 years) will be advised to have healthy food assuming that a large proportion of the school teaching will be through the computer network in the future.
   • If a university/individual develops a new process at a small scale, the inventor(s) can declare the innovation in the website for the purpose of scale-up and large scale processing by others including government and private bodies with mutually agreed terms.
   • Another website is required to develop where the R & D requirements of the country are reflected with active participations from industries, academic institutions, exporters and researchers.

Policy Issues

• Taxation on food products
  • Food for selling in the Indian market need to be taxed under three categories
  • Healthy food with low fat content (less than 5%) are to be taxed at the lowest level. Example of such food includes bread, whole-wheat flour, flaked rice, puffed rice, and raw and roasted cereal/pulse flour.
  • Neither healthy nor unhealthy food need a moderate taxation where the fat content is between 5 and 10%
  • Examples of such food are biscuit, less fat containing snacks, etc.

• Non-healthy food, having the fat content of more than 10%, are to be discouraged. Examples are high fat containing cookies and pastries, fried food like potato chips, etc. These food are to be taxed at the highest rate.

• The North Eastern Region, the Hilly States (J&K, HP and Uttarakhand), the Islands (A&N, Lakshadweep) and the Integrated Tribal Development Projects (ITDP) areas in the country need to be given fiscal incentives like excise duty/sales tax concessions and tax holidays only to the units established in those areas.

Food for Emergency Situation

• Natural calamities like cyclone, earthquake, flood and draught are common in India every year. It thus desirable to have five centres where long shelf life emergency food are kept appropriately for meeting the emergency needs. The locations may be in the north, east, west, south and north-east regions of the country where good road and air connectivity are available. The specific food (such as dry chapati, emergency ration, low fat baked products, compacted bars, etc) that are to be stored in these centres may be processed through different welfare schemes and should have shelf life of at least one year. If not needed or used within this time, they can be distributed after nine months of storage to the same welfare group persons/school children under nutritional intervention programme to avoid food wastage. A website indicating the name and quantity of food under storage should be made available to people so that the time of searching and preparation of food during such emergency are avoided/omitted. It becomes more relevant as the number of voluntary organisations to do this type of social activity is expected to reduce in the coming years.
4.0 RECOMMENDATIONS

Open web source complete with all data required for understanding the merits of such technologies and products, including those based on Indian traditional food, needs to be created.

Mechanisms for encouraging health, safe and long shelf-life food through appropriate laws and measures.

Rate of increase in population needs to be checked seriously to avoid shortage of food particularly the protein rich food and cooking oils.

Zero tolerance on the aspect of food adulteration.

Uniform syllabus on food technology/processing/engineering/preservation throughout the country at the graduate and post-graduate levels.

Implementation of food courts in urban areas to supply safe and low-cost food, and centralised kitchen facilities in rural areas.

Encourage Indian food to a global exposure.

Develop process lines for selected popular traditional food.

REFERENCES

Attractive characteristics such as light weight, high strength, high stiffness, good fatigue resistance and good corrosion resistance make it easy to fabricate structural parts using composites. India in 2035 should be able to realise the innovations in composite manufacturing, which has to produce results in rapid, high volume, cost effective and energy efficient composite manufacturing processes which will expand commercial and industrial utilisation.
Composites will materialize tomorrow’s sustainable future. Innovation in composites is of great importance to face the upcoming global challenges by providing safe and engineered materials with specific properties, new lean and precise processing technologies and novel recycling pathways in order to capture the full value of waste.

INDIAN SCENARIO
- In India, the first composites industry began in 1962. With the development of various industrial sectors, the Indian composites industry started growing. The Indian composites industry is currently expected to produce 320,000 metric tons per annum accompanying a market size of approximately USD 130B.
- With respect to its turnover the composites industry offers greater employment opportunities. It is currently employing 150,000 people either directly or indirectly. The composites industry in India manufactures around 35,000 implements.
- Statistics reveal that composites produced in India is equivalent to approximately 3% of the worldwide output and 6% of Asia’s output.

GLOBAL SCENARIO
- In 2010, the global composites industry was valued at USD 17.7 billion. This is expected to rise to USD 27.4 billion in 2016, thus growing by approximately 55%. Similarly, the end composites industry is estimated to increase to USD 78 billion in 2016 from USD 50.2 billion in 2010 thus attaining a growth of 55.3%
Indian composite industry to be a sustainable, technology driven, resource efficient and high productive manufacturing sector for delivery of a wide range of quality products.

- The confidence shown by the consumers towards the use of composites in the automotive industry has catalysed the composites industry to surge ahead.
- Global Automotive Composite Materials market was estimated to be around USD 2.9 billion in 2013, forecast to reach USD 5.7 billion by 2020 @ CAGR of approx. 8%.

**METHODOLOGY ADOPTED**

The procedures typically used for writing this vision document are stated. People from diverse backgrounds are consulted to arrive at a broad picture about the future of the Composite fabrication industry. Experts are asked to provide their thoughts and opinions for the four main stages of the road mapping process.

For each stage, after gather each input are then clustered under common topics and generally arrives at a consensus of opinion. Priorities are given to what are considered the most important issues for the last three stages of the road mapping process, enabling a key priority list to be established for each step. The final outcome is a list of priority items that need action in order to enable the industry to progress in a more dynamic and competitive manner.
DEMAND PROJECTIONS (2035)
Composite materials, which is evaluated to be 15K crores in India is expected to grow steadily and reach approximately 46K crore in 2035. The CAGR which is currently 15.6% is going to sustain its growth up to 2020 and from there grow aggressively until 2035 and the demand projections in KT for 2035 is estimated to be around 1123 at a increasing CAGR from 15-25.

- India’s continuous use of composites in applications such as rockets, satellites, missiles, light combat aircraft, advanced light helicopter and trainer is identical to that of the developed countries.
- The 3 emerging sectors in India for the usage of composite materials are Marine(31%), Wind Energy(28%) and Railway(20%)
- There is scope for further usage of composite materials in the building and construction sector: Rapid technological developments in the aerospace and defence sectors have been achieved with the use of composites. For instance, NAL and HAL have developed several components for the aerospace structural components using composites. This shows the ever growing presence of composites in modern projects.
- The Indian Automobile sector built on composites is expected to grow to USD 53.4B in 2035 from USD 32.5B in 2013 thus growing at a rate of 64.3%
INDIAN TRENDS
• The Indian chemical industry is greatly dependent on composites as certain requirements cannot be met by using traditional materials. Backed by a good chemical industry base this sector is characterized by its ability to tailor properties within a given part and develop complex shapes by employing low pressure tools.
• The increasing demand for developing indigenous materials for defence applications, possible two fold increase in non conventional energy usage, automobiles, railways and textiles is likely to aid the growth of this sector.
• Technology for recycling, avoiding high profile component failures, meeting increasing energy costs are some of the major requirements of this industry.
• Adequate support for building an IPR portfolio, skill development in design, developing indigenous machinery for manufacture, developing design data and tools, and specialized repair facilities are also essential for the growth of this industry.

GLOBAL TRENDS
• Automotive market has shown a positive growth after a setback in 2009, Significant interest shown by Automotive OEMs in developing carbon fibre applications
• The key growth drivers are automotive and aerospace applications, although demand from wind power and engineering sectors is also expected to increase
• To complement the rise in the use of composites in manufacturing, a 30% reduction in the cost of components is expected. However, process improvements, with a cost reduction of 40%, are more likely to increase cost savings
• Different technologies and components from various engineering segments – primarily from plastics machinery, textile machinery, machine tools in addition to the automation and handling systems need to be integrated to ensure the development of corresponding chains. This will reduce the transition period between process thus improving cost savings.
• Mostly, the firms are oriented towards improvement and fine-tuning in current practices, in view of the market size.

TECHNOLOGY GAP ANALYSIS
The Indian composite industry manufactures only FRP’s and GFRP’s in which almost 98% of the suppliers use hand-lay up or filament winding techniques. The applications are limited to aerospace and wind turbine blades due to the high manufacturing cost. The availability of raw materials for glass fiber has increased the growth of GFRP’s. Other fibres such as carbon and aramid are imported for higher costs. Although there is a steady growth for Indian composite industry for the last ten years the total volume of production is very low compared to other developed countries. The high cost of raw materials, lack of availability of many critical materials and obsolete technology for manufacturing has increased the cost of composite materials in India. Automotive applications of composite materials in India are limited due to productivity concerns which are because of non-mechanized manufacturing processes used. The skill level required in manufacturing of composite is high and therefore the Indian composite industry with its limitations is unable to compete with steel or aluminium.

Some of the technological gaps that the Indian composite industry lacks when compared to global players are listed below:
• Currently limited to low manufacture with high labour content.
• High raw material cost and lack of availability of materials
• No rapid automated production lines available
• No cost effective recycling strategies has been developed for composites
• Less skilled labour
• No standards or database available for materials
• Lack of knowledge in understanding composite supply chain
• No awareness among sectors for introducing composites
• Carbon fibre manufacturing & supply (Mostly imported and therefore costly)
• Lack of knowledge in design of products for composite manufacturing
• Integration of metals, thermosets, thermoplastics and other hybrids.
• Quality and testing facilities used are not up to the global standards
• No experience in analyzing composite material performance in high corrosive,
• There is a reluctance to try out new technology in this sector, delaying or even preventing the adoption of new materials and processes.

• The industry has historically used steel and there is a lack of relevant performance information, reference values or standards for composites to facilitate design and simulation.

3.0 TECHNOLOGIES FOR 2035

DRIVERS FOR COMPOSITE INDUSTRY
- Trend to life-style vehicles
- Lower weight and emissions
- For the high volume end the trend is towards including crash performance (compatibility)
- Towards hybrids for lighter weight and fuel economy
- Trends towards multi-functionality
- Replacement of metal
- Trends to move to modular construction

SECTORIAL DRIVERS
The general trends and drivers in four main application areas (automotive, aerospace, wind energy and engineering) of composite materials are

FOR AUTOMOTIVE
- Weight reduction and lower fuel economy
- Current applications are limited to areas in motor sports and premium / super premium segments

FOR AEROSPACE
- Increased composite usage in structural components for new aircraft types.
- Airbus A380 and Boeing B757 to carry almost 50% composite body structure.
- Interiors with high GFRP share
- State of the art helicopters and combat aircrafts

FOR WINDPOWER
- Rotor blades are exclusively made of GFRP’s
- Trend towards longer blades and high stiffness

FOR ENGINEERING
- High number of relatively small niche applications with varying requirements
- Use of high performance applications under extreme conditions

STRATEGIES FOR 2035

Cost/Productivity/Markets/Applications
Reduce the average cost of composite part by one-third, by providing better process selection guidance, increasing the use of automation and robots, and lowering reject and repair rates

Process Technology: Enhance the use of composite technology by developing state of the art composite technologies and disciplines, at the engineering level and also at the operational level.

Materials Technology: Develop newer composite materials and fibres

Quality Technology: Through the use of modelling, systematic process selection and procedure development, and NDE technologies, assure that composite technology is standardised and reduce rejections
Composite Industry, at every level, enabling them to make decisions that will result in utilization of the best technology for each application.

Energy & Environment: Reduce energy use in by 50% through such productivity improvements and enhanced recycling of composites.

STRAATEGIES FOR 2035

TECHNOLOGY AND PROCESSES

AUTOMATION

IMMEDIATE
- Make 80-90% of equipment compatible (“plug and play”) by developing an industry standard

MID TERM
- Use of sensors and other innovations from computer industries

LONG TERM
- Use systems technologies to integrate the process upstream and downstream

NEW TECHNOLOGIES

IMMEDIATE
- Orient fibres using draping, tow placement and nesting
- Introduction of hollow structure pultrusion processes
- Computer controlled filament winding machines
- Press forming of long discontinuous fibres
- Robotic thermoplastic ATP machine
- Co-curing of large structures in RTM

MID TERM
- Developing Reconfigurable mould that uses a liquid/particle media contained by membrane that solidifies against a master shape. The media can be re-liquefied and re-solidified, and can potentially be sculpted to net shape with a CNC machine.

LONG TERM
- Induction heating is used to selectively heat the mould for rapid cycling and low energy use compared to conventional heating

DESIGN

IMMEDIATE
- Evaluate composite techniques at design phase

MID TERM
- Conduct virtual qualification of Composite designs. Development of computational modelling tools which are important to assess life cycle impacts of composites

LONG TERM
- Develop software to simulate manufacturing processes and part service under various conditions

EDUCATION AND TRAINING

ENCOURAGING MORE STUDENTS TO PURSUE CAREER IN COMPOSITES AND IMPART QUALITY TRAINING

IMMEDIATE
- Significantly increase number of faculty and students in this discipline (→50%)

MID TERM
- Keep present stake holders in composites community aware of state-of-the-art technologies and processes

LONG TERM
- Double number of engineering programs focused on Composites and substantially increase composite-related information in the manufacturing - engineering curriculum
TECHNOLOGY ROADMAP: MANUFACTURING

ENVIRONMENTAL

- REDUCE ENERGY BY 50% AND ENSURE SAFETY AND HEALTHFUL ENVIRONMENT FOR WORKERS

**IMMEDIATE**
- Conduct energy audits and develop emission database for composite industries and benchmark with global industries

**MID TERM**
- Renewable energy Incentives, Green buildings Incentives
- Setting up green science parks for composites
- Applications of recycled fibres for composite production

**LONG TERM**
- Model all composite fabrication processes to identify and minimize environmental problems in both design and production stage

QUALITY AND MATERIAL TECHNOLOGIES

- REDUCE REJECTIONS

**IMMEDIATE**
- New generation of Statistical process control for Composite manufacturing

**MID TERM**
- Tools to address root cause of process unreliability
- Self-contained moulding system with a rapid heat up/cool down system

**LONG TERM**
- Develop harsh environmentally tolerant sensors

- ROBUST SIMULATION TOOLS

**IMMEDIATE**
- Development of Model based process control

**MID TERM**
- Tool to evaluate composite manufacturing process parameter effect on end service life of part

**LONG TERM**
- Mapping of Impact of simulation on shop floor performance

- ADVANCED MATERIALS

**IMMEDIATE**
- Develop a Composites material property virtual laboratory to determine the materials properties needed
- Production of Industrial grade PAN Precursors

**MID TERM**
- Develop long-lasting, reliable, corrosion-resistant materials
  - The durability of natural fibres, particularly their resistance to moisture, requires more investigation, e.g. high performance treatments to reduce moisture uptake and resistance to fungal attack
  - Prepreg materials are being developed to enable curing and acceptable properties without the capital investment for an autoclave

**LONG TERM**
- Increase product design community’s understanding of science of metallurgy, stimulate development of product designs and of new technologies and materials for composites

MARKET AND APPLICATIONS

- INCREASE GLOBAL DEMANDS OF COMPOSITE MATERIALS BY 50% IN 2035

**CONTINUOUS**
- Capture the demand for wind energy and auto segments for Asian markets; develop technology to ensure use of composites in airplanes; increase welding markets in engineering industries and also sustain development in aerospace industries
**ACHIEVE COST EFFECTIVE OPERATIONS**

**IMMEDIATE**
- Conduct “up-front” design and development (modeling, process/materials databases) to achieve a greater market share

**MID TERM**
- New conversion technologies that can heat fiber directly through the use of microwaves or a combination of microwaves and plasma to be developed

**LONG TERM**
- Enhance simulation of comprehensive techniques of production processes

**INCREASE PRODUCTIVITY**

**IMMEDIATE**
- Automate all the process from prepreg placement to Filament winding
- Quick cure without thermal effects. Need radiation shielding and resins designed for this process

**MID TERM**
- Reduce curing time for matrix materials by snap-cure techniques
- Tape Lay - a technique used to produce flat shapes through placement of wide prepreg tape accurately onto a tool. The lay-up (stack of tape) can be subsequently formed to a 3D shape.

**LONG TERM**
- Eliminate inspections, testing, and reworking as quality improves

**IMPROVE PROCESS AND PRODUCT**

**IMMEDIATE**
- Joining techniques such as bonding, adhesives, rivets and clinches
- Reconfigurable mold surface for rapid prototyping or repairs.

**MID TERM**
- Multi material design and Optimisation
- Use automatic curing process like ‘out of auto -clave’
- Curing of composites using electron beam

**LONG TERM**
- Superior methods of simulating production processes open up additional areas of potential

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**COMPOSITE RECYCLING**

With versatile application potential on one side, composites possess very limited scope of recyclability on the other hand, due to their inherent structural complexity. However, in case of composites where thermoplastics are used, recycling is possible through re-melting.

Mechanical grinding, pyrolysis, cement kiln route, fluidised bed, solvolysis are some of the prominent recycling process of composites. However, mechanical grinding and pyrolysis have proven to be commercially viable world wide. Recycled glass fibres through mechanical grinding find major applications in roofing industry while carbon fibres recycled through pyrolysis is used for electrostatic applications.

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### OVERVIEW OF RECYCLING OF DIFFERENT TYPES OF COMPOSITES

<table>
<thead>
<tr>
<th>TYPE OF COMPOSITES</th>
<th>RECYCLING METHODS</th>
<th>TECHNOLOGY FEATURES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermoplastic-matrix composites</td>
<td>Remelting and remoulding</td>
<td>No separation of matrix from the fibre</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Regrinding – compression or injection molding/extrusion – compression molding</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Product as pellets or flakes for molding</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fibre breakage – property degradation</td>
</tr>
<tr>
<td>Chemical recycling</td>
<td>Dissolution of matrix</td>
<td></td>
</tr>
<tr>
<td>Thermal processing</td>
<td>Combustion or incineration for energy recovery (option for old scrap)</td>
<td></td>
</tr>
</tbody>
</table>
### Recommendations

#### Technology
- India should extensively use composites in niche areas of the automotive, aerospace and marine industries.
- Thermoplastic composite structures have the potential to replace metal parts but more attention is needed to better processing and automation.
- Close attention needs to be given to the repair infrastructure, and the use of smart materials for damage assessment and correction.
- Recycling issues for composites need to be addressed, with issues such as identification, bonding and de-bonding, and re-use needing development work.
- Need for development of low cost indigenous technology for carbon fibre fabrication.

#### Skills
- Significantly increase number of faculty and students in composite manufacturing technologies.
- Double number of engineering programs focused on composites and substantially increase composite related information in manufacturing – engineering curriculum.
- Need for improved competence in computer-aided engineering, in crash, durability, and cost models.
- Create new coursework that places more emphasis on composite manufacturing technologies and on 3D design without the limitations of traditional manufacturing.

#### Enabling Innovation
- Establish national level composite manufacturing strategy.
- Increase R&D funding for cross cutting composite technologies.
- Establish national network of composite fabrication institutes.

#### Enhancing Capabilities
- Establish technical competencies that facilitate and accelerate the adaptation of progressive technologies, including rapid design and development, solid modeling for composite manufacturing.
- Provide resources at a reduced rate to help new companies get off the ground. This will help offset the high capital cost of equipment and operating expenses for start-up companies.
• Develop global standards for composite manufacturing processes
• Identify critical emerging technologies with transformational impact and capacity in translating these technologies into products and businesses for the market
• Support pre-competitive research and proprietary technology and product research, with a strong intellectual property (IP) protocol that favors manufacturers
• Establish distributed manufacturing support centers throughout the region to assist SMEs that want to adopt new technologies
• Provide a variety of business services such as design, digital manufacturing, prototype and test services for composite materials
• Involve quality assessments, accurately gauging worker skills

• Focus on energy efficiency and conservation
• Focus on composite recycling processes
• Improve cost competitiveness with traditional engineering materials

IMPROVE BUSINESS CLIMATE
• A set of specific tax reforms should be enacted that “level the playing field” for domestic composite manufacturers.
• Streamline regulatory policy for smarter regulation on composite manufacturing
• Effective and efficient legislative and regulatory frameworks
• Modify FDI policy to ensure transfer of technology by giving preference to JVs instead of 100% foreign owned companies
• Incentivize/mandate foreign players to increase value addition in India
• Preference in PSE/Government purchases for products having higher local content
REFERENCES


5. Yang et al., Chemical Engineering and Processing, 2012, 51, 53-68


Micro Nano Technology applied to manufacturing is an emerging field that enables production of several new innovative products in a wide spectrum of areas with vastly improved functionalities at much smaller scales of size and at considerably less cost. The micro nano manufacturing technology will have significant impact on improving energy harvesting, healthcare, water purification, sensors, environment remediation etc.
Micro / Nano Manufacturing is defined as the manufacture of components and products in the sub-micrometer to a few-millimeter range with micro / nano size feature characteristics of high accuracy and precision in a wide range of engineering materials by non-lithography based processes. The idea of micro/nano manufacturing was necessitated by the development of parts to be used in bio medical engineering, miniature sensors, aerospace and automotive equipment, optical and electronic equipment etc. The meso scale parts are manufactured with various processes like electrolytic in-line dressing (ELID), Electro-chemical machining (ECM), die sinking electro discharge machining (EDM), wire cut electro discharge machining (WEDM), milling, turning etc. While lithography based techniques are the most common for micro electronics manufacturing which cover a wide spectrum of products encompassing the entire ICT spectrum, micro and nano fabrication could be considered as an extension of conventional manufacturing in a limited sense. As the size of the products becomes increasingly smaller and the market for micro and nano scale parts is on the increase, the previous non-lithographic processes are required to be employed at the micro and nano scales. However, new nanofabrication techniques are evolving in the laboratories that are capable of creating nano structures and it is a matter of time before these become part of regular manufacturing on shop floors. During the last decade, the applications of nano technology in the form of incorporating nano scale features on macro parts like lenses, mirrors and bearings and nano scale devices for applications like drug delivery and other health related applications have emerged. These factors have motivated the development of micro and nano machines. Already, the lithographic processes have moved on to sub 30 nm thick wafers and thinner wafers are on development.

There are many fields of micro manufacturing. Rajurkar et al have given an interesting overview of micro nano machining.1 They can be broadly classified as: a) Mechanical micro-manufacturing, b) Electro physical and chemical micro-machining, c) Energy beam micro-machining, d) Near net shape micro-forming and micro-forging, e) Additive micro-manufacturing processes (including micro-casting), f) Micro-joining (including micro-welding, micro-soldering, micro-brazing).

Micro-manufacturing has been the topic of research for quite some time. Process modeling, optimization, technology development and machine building have been going on for three decades and more and several commercial applications are in place now.2-5 Nano scale manufacturing is the newly emerging area of manufacturing and the capability of several conventional machining processes has been extended to nano scale manufacturing. Emerging processes under this category are: a) Chemical vapour deposition, b) Physical vapour deposition, c) Molecular beam epitaxy, d) Atomic layer epitaxy, e) Dip pen
India to be a technology leader in Micro Nano Manufacturing by 2035, leveraging its strengths in precision engineering and backed by smart skilled workforce.

Micro Nano Manufacturing technologies have the potential to create economic growth in all developed countries of the world, particularly in India. While substantial work is going on in laboratories, technology transfer from lab to industry is yet to be achieved.

Globally, all major industrialized countries have been investing heavily in micro and nano manufacturing technology. During the last twenty years, a number of micro machines for drilling, milling, turning and electric discharge machining (EDM) have been developed and are already commercially available. A few machines have been developed for nano manufacturing. Physical vapour deposition (PVD) and chemical vapour deposition (CVD) machines of several configurations and types are available for additive manufacturing operations. Focused ion beam machines are used for chipping away materials at nano level. 3-D printers are available with micro level accuracy. Some 3-D printers with nano level accuracy have been reported from laboratories abroad.

Micro Nano Manufacturing technologies have the potential to create economic growth in all developed countries of the world, particularly in India. Over the next 10-20 years, projections by several organizations estimate that the global market for products will vary between US $ 2.6 Trillion to US $ 3 Trillion. This estimate is based on the optimistic assumption that these technologies have the potential to change every product in the market today. Based on an assumed CAGR of 12-15%, the market for micro nano manufacturing technology based products will be around US $ 8 Trillion. USA and European countries dominate much of the current market. If we give the right push to this technology through support for indigenous applied collaborative R&D, manpower development and appropriate policy initiatives, India could have a good share of global market.

**CURRENT INDIAN AND GLOBAL SCENARIO**

Micromachining research was initiated in most of India’s premier institutions about 10 years ago. A couple of attempts to develop indigenous machines have been reported. A single point diamond turning machine was successfully developed in India. Micro manufacturing received a fillip in India through National Program on Smart Materials (NPSM) and National Programme on Micro and Smart Systems and Structures (NPMASS). NPSM helped to create facilities in many institutions. NPMASS is focused on delivery of products.

The Nano initiatives of the Government of India funded major facilities, education programmes and research projects in many universities across the country. This has helped in increasing the number of publications. Synchrotron facility established in the country has enabled micro nano fabrication.

While substantial work is going on in laboratories, technology transfer from lab to industry is yet to be achieved.

Globally, all major industrialized countries have been investing heavily in micro and nano manufacturing technology. During the last twenty years, a number of micro machines for drilling, milling, turning and electric discharge machining (EDM) have been developed and are already commercially available. A few machines have been developed for nano manufacturing. Physical vapour deposition (PVD) and chemical vapour deposition (CVD) machines of several configurations and types are available for additive manufacturing operations. Focused ion beam machines are used for chipping away materials at nano level. 3-D printers are available with micro level accuracy. Some 3-D printers with nano level accuracy have been reported from laboratories abroad.

Micro Nano Manufacturing technologies have the potential to create economic growth in all developed countries of the world, particularly in India. Over the next 10-20 years, projections by several organizations estimate that the global market for products will vary between US $ 2.6 Trillion to US $ 3 Trillion. This estimate is based on the optimistic assumption that these technologies have the potential to change every product in the market today. Based on an assumed CAGR of 12-15%, the market for micro nano manufacturing technology based products will be around US $ 8 Trillion. USA and European countries dominate much of the current market. If we give the right push to this technology through support for indigenous applied collaborative R&D, manpower development and appropriate policy initiatives, India could have a good share of global market.

**METHODOLOGY AND APPROACHES FOLLOWED TO FORMULATE THE ROADMAP**

The roadmap has been prepared on the basis of interaction with all major researchers and seminars on micro nano manufacturing and advanced schools conducted in the country.

The draft roadmap was communicated to experts in the field in India. A few experts in India and abroad were contacted to elicit views on the forecast for future. The responses received were incorporated in the roadmap.
2.0 TRENDS IN TECHNOLOGY DEVELOPMENT

**DOMESTIC TRENDS**

In the case of India, micro nano manufacturing can be considered as an offshoot of the need for the strategic industries dealing with precision fabrication. All along, the strategic industries depended on machines manufactured by a few industries to manufacture precision components at macro and meso scales. Indian machinery manufacturers were either technologically incapable of reaching this level of precision or were not interested in R&D to extend their manufacturing in this range because of likely poor return from market. The reluctance of Indian industry to enter areas of product development like high-tech biomedical devices, sensors and precision instrumentation, could be considered as another factor which retarded the growth of this sector in India, though educational institutions, R&D organizations etc. have been actively involved in the promotion of this sector. Successful translation of technology to market has not been substantial.

**GLOBAL TRENDS**

All major industrialized countries are investing heavily in micro and nano technology. Considering the future potential of micro nano manufacturing many countries have invested heavily in R&D in these areas. Micro and nano manufacturing has been the focus of attention during the last 15 years. The application areas can be broadly classified into existing markets, emerging markets and consumer markets.

The technology has a number of enablers, some of that are already available (needs further developments) and others need to be developed through R&D. Some of the current application areas of this technology include sensors, energy materials and devices for hybrid solar energy, fuel cells, ultra capacitors, electronics industry, pharmaceuticals, drug delivery, smart, innovative and functional textiles, safety and security equipment, biomedical engineering, automotive and aerospace industry.

**TECHNOLOGY GAP ANALYSIS**

Evidently, there exists considerable gap between micro nano technology in India compared to advanced countries in Europe, USA, Korea, Taiwan and Japan. Nanotechnology has been given a big push through the Nano Mission of the Govt. of India. However, the focus so far is on manpower development and development of science and technology. The semiconductor electronics where nano technology made a significant impact does not have any significant footprint in India. We are also

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**APPLICATION AREAS AND ENABLERS**

<table>
<thead>
<tr>
<th>EXISTING MARKETS</th>
<th>CONSUMER MARKETS</th>
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<tbody>
<tr>
<td>• New engineered materials</td>
<td>• Improved white and brown goods</td>
</tr>
<tr>
<td>• Widespread introduction of sensors, Electronics</td>
<td>• Agriculture, food, commodities</td>
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<td>• Textiles, Apparel, Personal accessories</td>
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<table>
<thead>
<tr>
<th>EMERGING MARKETS</th>
<th>ENABLERS</th>
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<tbody>
<tr>
<td>• E-Mobility, Batteries, Engines</td>
<td>• New manufacturing equipment and automation techniques, micro and nano robots, Photonic machines</td>
</tr>
<tr>
<td>• Healthcare</td>
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<tr>
<td>• Environmental - water, energy</td>
<td>• Nano-Bio-Info integration with digital knowledge based tools</td>
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<tr>
<td>• Smart personal and home devices</td>
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lagging behind in utilizing nanotechnology in health care and energy. Printed electronics and organic thin film based solar PV is still in the laboratory level. However, the country is yet to see a viable and commercially successful engineering product yet.

As far as MEMS micro machining is concerned, India has established fabrication facilities and manpower development programs under the earlier NPsM project. The successor project NPMAss has a focus on product development and a few products are now marketed. Apart from a few organizations involved in the development of sensors, the industry as a whole is yet to embrace micro machining in a big way. Micro moulding and manufacture of micro parts by metal injection moulding have been reported. Unless there is a vibrant ecosystem of development of technology products and its rapid commercialization, technology development in the laboratories will be directionless. As such, there is a considerable gap in the technology in India compared to technology elsewhere.

This scenario is seen in the development of micro machine tools too. There is just one manufacturer of multi-function micro machine tool in India. Their output is also less because of the lack of support infrastructure. Though there are a number of indigenous developments, industry has been lukewarm in converting these technologies into viable products.

Nano fabrication can be classified under four categories: Nano particle manufacture, Manufacture of Nano surfaces, manufacture of Micro Nano components and Multi-scale System Integration. As far as manufacture of nano particles is concerned the technology gap is narrowing between India and advanced countries.

Many of the R&D labs and universities have set up the facilities for nano particle manufacture as a stage one of the development. Some of these (carbon nano tubes, nano wires, silver nano particles etc.) are also available commercially.

The second stage of development is the production of nano surfaces. The capability in India in this area is improving with the acquisition of several machines recently in different research labs across the country. The indigenous manufacturing capability is in CVD, PVD, and microwave assisted CVD.

The third level of development is manufacture of products with micro nano fabrication technology. There are four specific areas of development, viz., a) manufacture without product-specific tools as in additive manufacturing, b) micro tooling for subtractive manufacturing, c) components
with integrated functionalities like lab-on-the-chip and d) functional micro nano structures on meso and macro parts (Multi Scale Integration). Micro stereo lithography, single point diamond turning etc. is also picking up.

There exists considerable technological gap between India and developed countries at this level. Additive manufacturing and roll-to-roll manufacturing are disruptive technologies, which are likely to challenge many of the existing processes in future.

Typical example is implants for rehabilitation purposes where a nano meter level surface finish is needed.

Nano composites are important materials which are the used for manufacture of components. It must be noted that there are many more applications already implemented or emerging.

The fourth stage of micro nano based product development and manufacturing is multi-scale system integration. In a majority of cases micro nano components form part of a system, which has macro and meso scale components. Packaging and integration are major technological challenges here.
Scientists of Fraunhofer Institute in Germany have summarized the challenges to overcome in micro nano manufacturing. An entire spectrum of engineering activity needs to be developed to convert the science and technology from the laboratories. This involves equipment design, contamination control, cleanliness standards, process simulation software, clean room technologies, shop floor data gathering and control, factory automation and optimization.
Micro and nano manufacturing technology is of recent origin and newer and newer developments are reported frequently from R&D laboratories around the globe. It is difficult to envision what will be the driving technology in micro nano manufacturing two decades or more later. However, it can be safely assumed that quantum computing, molecular manufacturing and self-assembly could be the technologies which will have a profound influence in manufacturing sector in future.

Molecular manufacturing deals with the design and manufacture of extremely small electronic circuits and mechanical devices built at the molecular level of matter. Using molecular manufacturing and self-assembly scientists and engineers will be able to manipulate materials at the atomic level to build the smallest possible electromechanical devices, given the physical limitations of matter. It is expected that much of the mechanical systems that is known today will be transferred to the molecular level as some atomic analogy.

As envisioned by Drexler of MIT, as well as many others, this may lead to nano computers no bigger than bacteria and nano robots and nano machines which could be used as a molecular assemblers and disassemblers to build, repair, or tear down any physical or biological objects. Nano-robots will be able to carry out drug delivery, artery cleaning, removal of cancerous cells, surgical operations of the eye etc.

In essence, the development of nanotechnology is to have tools to work on the molecular level analogous to the tools we have at the macro level. Nano-machines will enable us to create a plethora of goods and increase our engineering abilities to the limits of the physical world.

Two major challenges, which need to be addressed for the development of micro nano manufacturing technology in India, are:

i. Creating adequate capabilities for nano structuring, coating, replication and characterization in India

ii. Developing, manufacturing and characterization equipment at an affordable cost.

Several products, which we use today, are likely to be manufactured better with more advanced and efficient performance features. Many of the silicon devices, which we use today, may be replaced using printed electronics. Roll to roll printing is likely to add a new dimension to additive manufacturing, enlarging the scope of additive manufacturing to the production of low cost electronic components, RFID tags, batteries, antennae etc. The following sections give an insight into how this technology will impact manufacturing in future. Only a few applications are mentioned here as micro nano technology spans the entire spectrum of materials and manufacturing.

ENERGY

The supply of energy is one of the great social challenges of the twenty-first century, at the global level, where alternatives to fossil fuels are needed, and also at the local level, where batteries often supply energy. Local energy supplies are becoming increasingly important for applications such as environmental monitoring with wireless sensor networks, implantable medical devices, tyre pressure sensors and traffic control systems.

The most advanced nanotechnology projects related to energy are i) storage, ii) conversion, iii) improving manufacturing processes by reducing material content and improving processing speeds, iv) energy saving by better thermal insulation, and v) enhanced renewable energy resources. Micro and nano fabrication technologies have helped the energy systems to be more and more compact, efficient and less expensive. Some of the examples of application are:

• Manufacturing of energy-related micro-devices
• Micro channels, micro fluidic ducts in...
foams, micro structured reactors etc.

- Fabrication of ceramic and metallic foams
- Catalyst-coating techniques
- Micro heat transfer devices, heat pumps etc. Used in computers, laptop, and other mini devices

In the long term, micro nano manufacturing technologies are unlikely to have a significant impact on the environment or on energy costs.

**Reduction of energy consumption:**
Micro nano technologies help to reduce energy consumption by better insulation systems, by the use of more efficient lighting or combustion systems and by use of lighter and stronger materials in the transportation sector. Light bulbs presently used convert only approximately 5% of the electrical energy into light. Nano-technological approaches like light-emitting diodes (LEDs) or quantum-caged atoms (QCA) could lead to low energy consumption for illumination.

**Increasing the efficiency of energy production:** Micro fabrication technologies have helped to improve the efficiency of power production. Nano technology has further helped to push the efficiency envelope and reduce the cost. The best solar cells manage to use 40 percent of the sun’s energy in spite of layers of several different semiconductors stacked together to absorb light at different energies. Commercially available solar cells have much lower efficiencies (15-20%). Tetrad-shaped nanoparticles when applied to a surface instantly transform it into a solar collector. Nanotechnology could help to increase the efficiency of light conversion by using nanostructures with a continuum of the band gaps.

Increasing the efficiency of the internal combustion engine is about 30-40%. Nanotechnology could improve combustion by designing specific catalysts with maximized surface area.

**More environment-friendly energy systems:** Environment-friendly form of energy is the use of fuel cells powered by hydrogen, which is ideally produced by renewable energies. Important nanostructured materials in fuel cells are the catalyst/support materials consisting of carbon-supported noble metal particles with diameters of 1 - 20 nm. Suitable materials for hydrogen storage contain a larger number of small Nano sized pores. Development of many nanostructured materials like nanotubes, zeolites or alanates is under research. Nanotechnology can contribute to the further reduction of combustion engine pollutants by nano porous filters, which can clean the exhaust mechanically, by catalytic converters based on nano scale noble metal particles or by catalytic coatings on cylinder walls and catalytic nanoparticles as additive for fuel.

It is possible to develop both secondary and primary batteries with high-energy densities, high capacities using nanomaterials. It is also possible to achieve high rate charge/discharge cycles.

Nanotechnology is poised to make significant improvements in solar energy harvesting. Use of hybrid solar energy devices, flexible solar films, use of nano tubes and nano wires to increase the efficiency of electron transport etc. have opened up new possibilities. 

**CHEMISTRY AND ENVIRONMENT**
Chemistry is closely associated with the fabrication of several chemical sensors. Chemical catalysts and filtration techniques are the areas in chemistry in which micro and nanotechnology play an important role. The synthesis provides novel materials with tailored features and chemical properties like nanoparticles with a distinct chemical surrounding (ligands), or specific optical properties. In this aspect, chemistry is to be considered as a basic Nano science. Chemistry will provide novel “nanomaterials” in short term and superior processes such as “self-assembly” will enable energy and time-preserving strategies in the long run.

**Catalysis:** Catalysis is important for the production of chemicals. Chemical catalysis benefits from nanoparticles, due to the large surface-to-volume ratio. The application of the nanoparticles in catalysis is from fuel cell to catalytic converters and photo catalytic devices.
**Filtration**: Micro channel based filtration is becoming widely adopted in several cases. Metallic micro nano filtration systems are being increasingly tried out in water purification systems. Micro fabrication techniques have helped to improve filtration efficiency. Influence of Nano chemistry on wastewater treatment, air purification and energy storage devices is on the anvil. Mechanical as well as chemical methods can be used for effective filtration techniques. Nano porous membranes (may be composed of nanotubes) with extremely small pores smaller than 10 nm are suitable for a mechanical filtration. Nano filtration is mainly used for the removal of ions or the separation of different fluids. The membrane filtration technique is named ultrafiltration, which works down to particles of size 10 to 100 nm. One important field of application of ultrafiltration for medical purposes is in renal dialysis. By making use of magnetic separation techniques, magnetic nanoparticles offer an effective and reliable method to remove heavy metal contaminations from wastewater. Nano particles increase the efficiency to absorb the contaminants and this method is inexpensive compared to traditional precipitation and filtration methods.

**INFORMATION AND COMMUNICATION**
Micro technology has contributed to the rapid growth of ICT. In high technology production process, the introduction of nanotechnology has already made a mark. The gate length of transistors used in CPUs and DRAM is at the nanoscale especially the critical length scale of integrated circuits used in them. Wafer thicknesses are now at sub 30 nm levels. Eventual replacement of silicon with carbon is emerging as a distinct possibility.

**Memory storage**: Electronic memory designs in the past have largely relied on the use of transistors. Research of crossbar switch-based electronics had provided an alternative using reconfigurable interconnections between vertical and horizontal wiring arrays to create ultra-high density memories. Two types of memory storage are:

i. A carbon-nanotube-based crossbar memory called nano-RAM.

ii. The use of memristor material as future replacement of flash memory.

**Novel semiconductor devices**: Novel semiconductor devices are based on spintronics. The dependence of the resistance of a material (due to the spin of the electrons) on an external field is called magneto resistance. This effect can be significantly amplified for Nano sized objects. A giant magneto resistance (GMR) effect has led to a strong increase in the data storage density of hard disks up to gigabytes. The tunneling magneto resistance (TMR) is similar to GMR and based on the spin-dependent tunneling of electrons through adjacent ferromagnetic layers. Both GMR and TMR effects can be used to create a non-volatile main memory for computers, such as magnetic random access memory (MRAM).

**Novel optoelectronic devices**: In modern communication technology, traditional analog electronic devices are increasingly replaced by optical or optoelectronic devices due to their large bandwidth and capacity, respectively. Two areas of importance are photonic crystals and quantum dots.

i. Photonic crystals are materials with a periodic variation in the refractive index with a lattice constant that is half the wavelength of the light used. They offer a selectable band gap for the propagation of a certain wavelength and they resemble a semiconductor, but for light or photons instead of electrons.

ii. Quantum dots are nano scaled objects used for the construction of lasers. The advantage of a quantum dot laser over the traditional semiconductor laser is that their emitted wavelength depends on the diameter of the dot. Quantum dot lasers are cheaper and offer a higher beam quality than the conventional diodes.

**Displays**: The production of displays with low energy consumption is possible using carbon nanotubes (CNT). Carbon nanotubes can be electrically conductive and can be used as field emitters with extreme high efficiency for field emission displays (FED) due to their small diameter of several nanometers. The principle of operation is like the cathode ray tube on a much smaller length scale.

**Nano logic**: Nano scale devices exhibit dominant nonlinearities that prevent their use
as two-state devices in digital computers. The idea behind Nano logic is to exploit these nonlinearities instead of suppressing them to implement functions that correspond to mathematical sets like interval numbers, disjoint intervals, fuzzy numbers, fuzzy sets, etc. Simple Nano electronic circuits can be designed that can represent sets and set operations, and an array of such devices constitutes a universal mathematical processor, able to solve any problem that can be expressed in set theory. Nano logic will help to solve problems involving uncertainty, ambiguity, error, under-specified and over-specified systems, and for approximate analysis of combinatorial intractable problems, including mathematical theorems, etc.

Quantum computers: New approaches for computing use the laws of quantum mechanics for novel quantum computers, which enable the use of fast quantum algorithms. The quantum computer will have quantum bit memory space termed qubit for performing several computations at the same time.

MICRO AND NANOTECHNOLOGIES IN MEDICINE
Micro fabrication has been used for many applications in biology and medicine. These applications fall into four domains: tools for molecular biology and biochemistry, tools for cell biology, medical devices, and biosensors. Micro fabricated device structures have significantly enhanced performance with respect to conventional devices. Micro fabrication can enable devices with novel capabilities. These enhancing and enabling qualities are conferred when micro fabrication is used appropriately to address the right types of problems. Extending the scale to nano level, biological and medical research utilized the unique properties of nanomaterials for various applications like contrast agents for cell imaging and therapeutics for treating cancer. Biomedical nanotechnology, bio-nanotechnology, and nanomedicine are the other nomenclatures for this hybrid field. Functionalities can be added to nanomaterials by interfacing them with biological molecules or structures. The size of nanomaterials is similar to that of most biological molecules and structures. Because of this property, nanomaterials can be useful for both in vivo and in vitro biomedical research and applications. The integration of nanomaterials with biology has led to the development of nanomaterials with biology has led to the development of nanomaterials with biology has led to the development of nanomaterials with biology has led to the development of nanomaterials with biology has led to the development of diagnostic devices, contrast agents, analytical tools, physical therapy applications and drug delivery.

Diagnostics: Point-of-care (POC) diagnostic instruments typically employ a disposable test cartridge in conjunction with a sensitive reader. Given the requirement for quantitative measurements with reduced sample volumes, micro fabrication technologies are emerging as the prime means to deliver the required measurement precision. Micro fluidics and bio MEMS are accepted technologies in medical diagnosis. Lab-on-the-chip concept has become a reality with micro fabrication. Nanotechnology has further advanced lab-on-a-chip technology. Biological tests measuring the presence or activity of selected substances-become quicker, more sensitive and more flexible when certain nano scale particles are put to work as tags or labels. Some specific applications of nanotechnology in diagnostics are:

i. Magnetic nano particles, bound to a suitable antibody can be used to label specific molecules, structures or microorganisms.

ii. Gold nanoparticles tagged with short segments of DNA can be used for detection of genetic sequence in a sample.

iii. Multicolor optical coding for biological assays has been achieved by embedding different-sized quantum dots into polymeric micro beads.

iv. Nano pore technology for analysis of nucleic acids converts strings of nucleotides directly into electronic signatures.

Drug delivery systems: In recent years, considerable research and development has taken place in the field of novel micro fabricated and nanofabricated devices for drug delivery. Such devices seek to develop a platform of well-controlled functions in the micro- or nano-level. They include Nano particulate systems, recognition of molecular systems, bio-sensing devices, and micro fabricated and microelectronic devices. The drug dosage as well as side effects of the drugs can be reduced by depositing the active drug in the diseased tissues only.
thereby reducing the need of higher doses. This target-oriented approach saves time and money and reduces human suffering.

Nanotechnology-oriented implantable drug delivery system is preferable to the use of injectable drugs. Injectable work on first-order kinetics namely the blood concentration goes up rapidly, but drops exponentially over time. This will increase drug toxicity, and drug efficacy is unpredictable as the drug concentration falls below the targeted range.

Some specific applications in drug delivery systems are:

i. Dendrimers and Nano porous materials could hold small drug molecules, transporting them to the desired locations.

ii. Applications based on small electromechanical systems such as NEMS are researched for the active release of drugs. Important applications of this include, treatment for cancer with iron nanoparticles or gold shells.

**Tissue engineering:** The fast growing field of regenerative medicine promises significant progress in the treatment of several ailments like arthritis, joint wear, cardiac ischemia, liver disease, and spinal cord injury. Key to its success will be the ability to engineer tissue safely and reliably. Nanotechnology can help to reproduce or to repair damaged tissue. This “tissue engineering” makes use of artificially stimulated cell proliferation using suitable nanomaterial-based scaffolds and growth factors. Tissue engineering might replace conventional treatments like organ transplants or artificial implants. Advanced nanotechnology-based tissue engineering can also lead to longevity of life in a matter of years. But, the concept of tissue engineering is a matter of debate on ethical grounds like that of human stem cells.

**Biomaterials including implants and devices for rehabilitation:** Manufacture of biomaterials, implants and artificial limbs require extensive application of Micro Nano Manufacturing technologies.

**LARGE SCALE MANUFACTURING**

An inevitable use of nanotechnology will be in large-scale manufacturing.

**Aerospace:** Lighter and stronger materials will be of immense use to aircraft manufacturers, leading to increase performance. Spacecraft, where weight is a major factor, will also benefit. Micro and nanotechnology thereby primarily helps to reduce the size of equipment used. Aerospace systems will benefit from micro fabrication technology due to reduced size, mass and power requirements for many standard functions. Micro fabrication can also enable precise control of surfaces and fluid dynamics.

There are several reported applications of nano technology in aerospace engineering. Through the use of nanotech materials, the weight of hang-gliders is reduced considerably while increasing their strength and toughness. Nanotechnology helps in lowering the mass of super capacitors that are used to give power to assistive electrical motors for launching of hang-gliders. In addition, nano technology offers new types of thin coatings for aircraft for protection against corrosion as well as for specific military applications.

**Construction:** Nanotechnology can make construction faster, cheaper, safer and more varied. Automation of nanotechnology construction can allow for the creation of structures from advanced homes to massive skyscrapers much more quickly and at much lower cost. Use of carbon nano tubes has helped to improve the strength of reinforced concrete. Micro and nano technology has applications in clinker production, improving wood and glass, specialty coatings, fire protection and detection equipment etc.

**Primary metal manufacture:** Processes that produce materials such as steel and aluminium will be able to remove any impurities in the materials with the application of nanotechnology.

**Vehicle manufacture:** Micro nano fabrication has helped in improving several automotive systems like ECU, sensors, lubrication etc. Lighter and stronger materials will be useful for creating the vehicles, which are faster and safer. Combustion engines will also benefit from parts that are more wear and heat resistant. Automotive systems will benefit
from micro and nano engineering technology due to reduced size, mass and power requirements for many standard functions. Better tyres can be developed using nano technology. Nano technologies also help to promote sustainability and safety.

**Consumer goods manufacturing:**
Nanotechnology is making an impact in the field of consumer goods, providing products with novel functions ranging from easy-to-clean to scratch-resistant.

**Food:**
Nanotechnology can be utilized in the production, processing, safety and packaging of food. Nano composite coating process could improve food packaging by placing antimicrobial agents directly on the surface of the coated film. Nano composites could increase and decrease gas permeability of different fillers as is needed for different products. They can also improve the mechanical and heat-resistance properties and lower the oxygen transmission rate. Research is being performed to apply nanotechnology to the detection of chemical and biological substances for sensing biochemical changes in food.

**Household appliances manufacturing:**
The nanotechnology applications in the household items and equipment aim at self-cleaning or “easy-to-clean” surfaces on ceramics or glasses. Common household equipment like flat irons when made with nanoceramics particles has improved the smoothness and heat resistance.

**Optics:**
The sunglasses using protective and antireflective ultrathin polymer coatings are available. For optics, scratch-resistant surface coatings based on nanocomposites are used. Nano-optics could allow for an increase in precision of pupil repair and other types of laser eye surgery.

**Textiles:**
The use of engineered nano fibres makes clothes water- and stain-repellent or wrinkle-free. Textiles with a nanotechnological finish can be washed less frequently and at lower temperatures. Nanotechnology has been used to integrate membrane containing tiny carbon particles and guarantee full-surface protection from electrostatic charges for the wearer. Modern textile products are wrinkle-resistant and strain-repellent. Soon, clothes will become “smart”, through embedded “wearable electronics”

**Cosmetics:**
 Especially in the field of cosmetics, products incorporating nano particles have a promising potential. The traditional chemical UV protection approach suffers from its poor long-term stability. A sunscreen based on mineral nanoparticles such as titanium dioxide offer several advantages. Titanium oxide nanoparticles have a comparable UV protection property as the bulk material, but lose the cosmetically undesirable whitening as the particle size is decreased.

**3-D Printing:**
3-D printing is emerging as one of the manufacturing technology of future. Manufacture of several products in plastic printed electronics, hybrid solar energy, low cost sensors and functional textiles will increasingly make use of 3-D printing technology more likely to be in the form of roll to roll printing. Multiscale manufacture using 3-D printing opens up enormous opportunities to develop products with enhanced functionalities. Manufacture of nano structures using fiber laser is being pursued in many laboratories and will be commercially exploited in large scale in the near future.

**DRIVERS**
In order to achieve the vision of India becoming one of the leaders in micro nano manufacturing, it is necessary to identify the drivers which will provide the necessary impetus for development of the science, technology and engineering connected with product development in this field.

I. **Innovation**, which should happen in a synergetic manner in academia and industries. Micro nano manufacturing technologies span a wide spectrum of industries. Micro Nano manufacturing technology being a multi scale technology, innovation can lead to several novel products. Textile, energy, water, food processing, mobility, materials, biomedical devices etc. are critical segments and a joint academia/industry innovation initiative will be helpful to promote product development.

II. **Research** is necessary to carry out extensive research to assess the impact
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<tr>
<th>TECHNOLOGIES FOR 2035</th>
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<th>2020-2030</th>
<th>2030-2035</th>
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<td>BIO-MEDICAL</td>
<td>Sensors, cardiovascular and in vitro diagnostic devices, cardiovascular clot removal catheters, medical implants, targeted drug delivery systems</td>
<td>Controlled drug delivery systems, Engineered replacement tissues, artificial skin and hair</td>
<td>Artificial organs, bones, self assembled organs</td>
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<tr>
<td>MATERIALS</td>
<td>Novel materials, Materials with enhanced properties</td>
<td>Tailor made materials</td>
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<td>ENERGY</td>
<td>Energy harvesting from unconventional sources, Batteries with efficient charging and discharge characteristics, ultra capacitors</td>
<td>Hybrid solar energy, hydrogen energy, Efficient fuel cells, micro-scale fuel cells</td>
<td>Widespread adoption of decentralized energy harvesting using devices made by additive manufacturing</td>
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<tr>
<td>WATER</td>
<td>Filtration devices</td>
<td>Large scale bacterial water purification</td>
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<tr>
<td>COMPUTING</td>
<td>Foldable displays, miniaturization, new memory devices</td>
<td>Quantum computing, Computing based on nano tubes</td>
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<tr>
<td>FOOD PROCESSING</td>
<td>Shelf life enhancement, sensors for quality monitoring</td>
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<tr>
<td>SMART TEXTILES</td>
<td>Wearable electronics, specialty textiles</td>
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<tr>
<td>AEROSPACE</td>
<td>Micro nozzles for high-temperature jets, dust resistant coatings</td>
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<tr>
<td>INFRASTRUCTURE</td>
<td>Use of nano fibres for reinforcement</td>
<td>Energy harvesting glass, brick</td>
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<tr>
<td>AUTOMOTIVE</td>
<td>Sensors for internal and external monitoring, waste heat converters, wireless devices for vehicle to vehicle communication</td>
<td>Energy harvesting paints</td>
<td>Sensors for driverless vehicles</td>
</tr>
</tbody>
</table>
of scaling laws on manufacturing process and equipment. Research is also needed for continuous assessment of science, gaps, deficiencies, and the need for fundamental knowledge. Understanding of multi-disciplinary science based requirements needs coordinated research involving several institutions.

III. Technology. Miniaturization in manufacturing needs new approaches and knowledge in equipment design, work handling, simulation and optimization. Bridging between macro- to meso- to micro- to nano- requires extensive fundamental and applied research. It is also necessary to make available proof of concept test beds for accelerated product development.

IV. Standardization. If a healthy industry is to be developed it could be done only through the development of standards for processes and products.

V. Commercialization. The economics of micro and nano scale manufacturing has to be carefully assessed. Societal benefits and broad based impact of miniaturization have to be weighed against the attendant risks of adopting this technology. Possibilities of creation of disruptive manufacturing technologies are also being considered in this context.

Challenges related to human resource and capacity building
In order to achieve the objective of promoting micro nano manufacturing technology, the following challenges should be addressed:
- Lack of adequate research infrastructure
- Lack of adequately trained researchers
- Lack of indigenous processing, characterizing and metrological equipment
- Lack of design, modeling, simulation and optimization know how.
- Need for more academic programs in science and engineering pertaining to this field
- A government industry consortium for understanding and identifying current and future applications and funding support.

POLICY ISSUES
Since micro manufacturing is critical to many sectors of manufacturing and in particular to national security and defence, energy and health care, encouragement to develop this sector is important to improve our manufacturing base. The following policy initiatives are suggested to promote R&D leading to commercially successful products.

a. Micro manufacturing should be a priority R&D area
b. Industry-university-government partnerships in S&T should be promoted
c. A decisive role by the government is important in funding machinery development projects in this area. Equally important is the development of cost effective metrological equipment as it is not possible to manufacture unless it can be measured.
d. Large-scale collaborative research projects with focus on product development could be launched in specific areas like health care, defence, nutrition and food, energy, water purification and environmental remediation.
e. Since nanoscience and nanotechnology is multi-disciplinary, it is necessary to develop an integrated approach for developing manpower covering disciplines like physics, chemistry, bio, composite materials, electronics etc. into one single training umbrella and more focus is needed in the educational system to train the students to handle manufacturing of nanotech materials and products. Special vocation educational programs, specialized training programs are some of the suggestions.
f. Government funding should be focused on developing skilled manpower in micro-and nano manufacturing and service sectors now since the fruits of investments in R&D will start yielding results.
g. Tie-up between industry and R&D institutions is another method of transferring the research outcome in nanotechnology to industry. The manpower of the industry could be trained to handle nanotech processes in production by R&D institutions.
h. Continuous training and retraining is required in the nano domain to keep the employees updated with the latest inputs.

BENEFITS FOR STAKEHOLDERS
The developments in micro nano manufacturing will improve the industrial base and diversify the manufacturing activities in a high priority area. New technology industries
will be set up and Indian industries can aspire to get a share of the emerging global market apart from meeting the local demand. In addition, the investment in micro nano manufacturing will lead to several benefits like
- additional job creation
- improvement of quality of life
- availability of energy at lower cost
- cheaper electronics and display products
- cheaper and more efficient measuring/monitoring devices, sensors, drug delivery systems, lab on chip devices
- value added textiles covering smart textiles, wearable electronics, anti microbial clothing, anti wetting clothing etc.

TECHNOLOGY INTERVENTIONS
There are several ways of technology interventions that can be pursued
• Development of micro nano manufacturing technology requires development of knowhow for manufacture of nano materials, processing equipment, metrology equipment, development of indigenous machinery for fabrication etc.
• Acquisition: While the country has moved ahead with capacity building in MEMS related technologies, we may need acquisition of knowhow in terms of ink preparation for additive manufacturing, 3-D printing technology, energy materials, photonics to name a few.
• Adaptation: Many micro nano-manufacturing issues can be handled through technology adaptation. This involves using the technology available in public domain to solve country specific problems. For instance, decentralized energy harvesting could be carried out through use of indigenous dyes as well as earth abundant coating materials available in India.
• Substitution: Micro nano manufacturing technology is heavily material dependent. Globally competitive manufacture needs the development of alternative materials for applications related to energy harvesting, healthcare, batteries, fuel cells, biomedical and strategic applications.

4.0 RECOMMENDATIONS

POSSIBLE TECHNOLOGY OPTIONS – DIRECTIONS TO STAKEHOLDERS
Micro Nano manufacturing is still at the beginning of a long journey. Micro nano manufacturing is perceived to be an important enabling technology along the innovation chain. The manufacturing challenges include various issues covering production of nano materials, micro and nano scale surface finishing, micro nano integrated components and their integration in products, industrial solutions and services and societal challenges.

Considering the scenario of development in other countries, the following activities are proposed for the development of this technology in India.
For manufacturing nano materials:
• Continuous energy efficient flow of raw materials to bulk nano material production without any in process leak

For manufacturing micro components:
• Extending the range of micro-fabrication capabilities in terms of materials, geometry and accuracy
• Compatible manufacturing processes for single and multi-material micro components
• New production methods for near monolithic integration

For manufacturing micro and nano surfaces:
• Robust surfaces with controlled shape and size
• Optimized functionalities of surfaces for better performance
• Higher flexibility and capability for textured nano finishing for self-assembly

The manufacturing challenges include various issues covering production of nano materials, micro and nano scale surface finishing, micro nano integrated components and their integration in products, industrial solutions and services and societal challenges.
• Bridging the gap between mechanical ultra precision fabrication and MEMS and IC fabrication
• Multi scale integration in new products

For system integration in micro and nano manufacturing:
• Knowledge based micro and nano manufacturing platforms
• Simulation systems for integrated meso, micro and nano platforms
• Design tools, test beds and equipment for low cost modular miniaturized equipment (desk top factories)
• Meso, micro and nano integrated process, supply chain, logistics and materials management
• Multi-function integration capability
• Traceability
• Management of toxicity

RECOMMENDATIONS
a. Form a national group of R&D organizations, industries, and possible end users of micro and nano enabled components and devices.
b. Develop standards for testing and qualification.
c. Embark upon a program for the manufacture of equipment for Micro and Nano research and development including scaling up from prototype to lot and mass production.
d. Develop standards for handling, disposing, and storing of nano particles.
e. Promote breakthrough research with a strong focus on innovation.
f. Focus on growth and value creation.

ACTION PLAN
Five focal areas are identified for a coordinated action plan. These include building momentum in R&D, development of infrastructure, human resource development, developing an ecosystem to promote innovation and finally carrying out all the activities with the right amount of emphasis on the societal dimension covering risk to humans and environment. The action plan in each of these areas is briefly outlined in the subsequent section
• Building momentum in R&D in Micro Nano manufacturing technologies: To reach the forefront of nano sciences and nanotechnologies, India should identify this as a core technology for future.
  - Substantially increase public investment in nano sciences and nanotechnologies, India should identify this as a core technology for future.
  - Next Generation Photo Voltaics
  - Hydrogen Energy
  - Fuel Cells
  - Efficient Batteries
  - Ultra Capacitors
  - Consolidation of MEMS Market
  - Sensor Networks for Agriculture, Food Processing, Transportation and Storage, Defense and Disaster Management
  - Innovation Textiles
  - Replacement of part of Subtractive Manufacturing by Additive Manufacturing
  - New material Design

Medical Applications
Sensor Fusion
Micro fluidics for diagnostics
Hybrid Solar Energy
Functional Textiles
Tailored Materials
Know how for producing Nano Particles, Surfaces, Structures and Multiscale System Integration

Self Assembly
Nano Robots for drug delivery and treatment
Quantum Computing
Molecular Manufacturing

2014 2020 2030 2035
- Promote excellence in nanoscience and nanotechnology by extending generous funding to a few hundred engineering colleges and arts and science colleges to create basic facilities for research. This research support should be for manpower, and allow them to use the fabrication and characterization facilities set up in the premier institutions expanding the scope and funding.
- Boost R&D in nanotechnologies with a view to wealth-generating applications with emphasis on the involvement of SMEs.
- Maintain a concentration of R&D activities in the next few years in order to create critical mass and synergy between the developments of nano sciences, nanotechnologies, and related engineering and safety aspects.
- Ensure effective coordination among various agencies funding R&D programs.

**Infrastructure development:** World-class infrastructure (“Centres of excellence”) is crucial to ensure that India improves its competitiveness in micro nano manufacturing technology R&D. This requires the following actions:
- Develop a coherent system of R&D infrastructure, taking into account, the needs of stakeholders, in particular, and developing synergy with education.
- Take measures in order to maximize the added value of existing infrastructure taking into account the needs of industry, in particular, SMEs, and start-ups.
- Accelerate progress in micro and nanotechnology manufacturing, in particular, interdisciplinary R&D.
- Set up more micro nano technology manufacturing institutes in the country to meet industry requirements.

**Developing human resources:** This can be both extension of the scale of existing technologies as well as a new field in some respects. Human resource development can therefore be carried out by:
- Incorporating in the existing manufacturing programs.
- Designing new educational programs.

This can be achieved by:
- Identifying the educational needs.
- Encouraging the definition and implementation of new courses and curricula, teacher training and educational material for promoting interdisciplinary approaches to nanotechnology both at graduate and postgraduate levels as micronano manufacturing technology is multi-disciplinary and product development requires considerable modeling and simulation knowhow most of which are not available in public domain.
- Integrate complementary skills into post-graduate and life-long training, e.g. entrepreneurship, health and safety issues at work and patenting.
- Create national level competitions and awards that would contribute towards encouraging the interdisciplinary and entrepreneurial spirit of researchers.
- Introduce skill development programs to train manpower to operate clean rooms and equipment.
- Developing an eco-system to promote entrepreneurship: The vision of making India a major player requires a coordinated approach to stimulate innovation and entrepreneurship based on micro and nanotechnology. The following steps are recommended:
- Societal issues related to micro nano technology and environmental impact: Micro and nano manufacturing, latter in particular involves considerable risk in manufacture, storage, transport, handling etc. The environmental impact is yet to be fully understood or assessed. It is therefore necessary to:
  - Focus on public awareness and confidence;
  - Be committed to ethical principles in the use of micro nano manufacturing technology.
  - To identify and address safety concerns regarding risk to health of users and workers and environment.
  - To generate data on toxicology and ecotoxicology.
The future of nanotechnology is completely uncharted territory. It is almost impossible to predict everything that nanoscience will bring to the world considering that this is such a young science. However, there are possibilities of several interesting and disruptive technologies emerging in future.

POLICY CHANGES
A multi institutional program with significant amount of funding should be launched with the objectives of development of products in areas of national priorities related to energy, water, sustainability, defense, infrastructure, and shelter.

Other support mechanisms, which should be put in place, are:
- Technology business incubation support in this area
- Encouraging industries and their associations to engineer these products for commercialization under PPP mode
- The Government of India may adopt conditions that promote investment in R&D by industry and new innovative enterprises based on micro nano technology
- Proactive support mechanisms to enlarge and strengthen the seed funding and capital base for innovation in micro nanotechnology manufacturing
- The government must put in place an affordable IPR framework to promote technology transfer and innovation.
- Emphasis must be placed on equipment development both for manufacture and metrology, and development of necessary standards for product specifications and performance.

Foresight Institute has done excellent work on nanotechnology ethics, including technical standards and policies. The Centre for Responsible Nanotechnology has been formed to advance the safe use of molecular nanotechnology and the Nano ethics Group focusses on the ethical and social implications of nanotechnology.

REALISING THE ROADMAP
This roadmap is drawn up to make India a dominant player in micro nano manufacturing technology. Leveraging our known strengths in precision manufacturing, the large pool of scientific and engineering manpower and good R&D and academic institutions, we will be in a good position to be a global leader in about two decades.

On one side, we must look at basic manufacturing technologies and on the other side the support mechanisms and the technologies needed to be developed and mastered.
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GLOBAL LEADER
India to be Global Leader in Micro Nano Technology by 2035

- Safety in storage, transportation in use, Risk assessment
- Nano particles, Nano surfaces, Nano structures System integration
- Defined standards for hardware and software
- Self auto adaptive intelligent, self controlling process
- Mass production of intricate nanoscale structures

TODAY
2016

2020

2025

2030

2035
India has the ambiance to emerge as a leading global manufacturing hub in Information Communication and Electronic Technologies leveraging the availability of young, knowledgeable Science, Engineering and Technology manpower. A joint effort between Government, Industry and Academia would make India realize its potential in the area of ICET products and services.
Electronics industry is one of the largest and fastest growing industries globally. The industry in India is also on an upswing. Even during the economic downturn, the consumption of electronic goods in India witnessed moderate growth, predominantly due to increasing demand for consumer goods and mobile devices. With the global economy showing strong signs of recovery, this growth is expected to continue in the long term. Though not on par with consumption, local production of electronics has also seen a boost, influenced by IT, wireless handsets, and communication equipment production in the last decade with foreign investment and technology. These segments collectively hold a share of 80% of total electronics market revenue in the country. In the last couple of decades, semiconductor chip design has grown rapidly in India. With many of the top 25 companies in the global semiconductor business setting up design houses in India, the country is progressing towards being a global semiconductor design hub, with Indian talent pool as the human resource. The progress in design segment has not translated into manufacturing as the top manufacturers have established facilities in their countries of origin. This situation is likely to change due to favourable governmental policies.1-5

CURRENT INDIAN AND GLOBAL SCENARIO
The electronic industry, more so consumer electronics, in India is growing fast. A market value of US$ 400-480 billion (US$ 340 billion from consumer electronics alone) is forecasted for 2020, which is only a miniscule (1.44%) of the forecasted global production of US$ 1.8 trillion.

The demand for electronics in the Indian market is growing rapidly. Growth of demand for telecom products such as mobile phones, computer and IT products, auto electronics, medical, industrial and consumer electronics is likely to bring in investments to augment Indian manufacturing capacity. India is also an exporter of a vast range of electronic components and products for many segments4,5 with the help of foreign investment in India.

The impressive growth of Indian economy offers excellent opportunity to electronic players worldwide. In consumer electronics, major global players have made commitments, by establishing large manufacturing facilities and now enjoy a significant share in the growing market for products such as televisions, CD/DVD players, audio equipment and other entertainment products. The global semiconductor industry is dominated by USA, South Korea, Japan, Taiwan, Singapore and European Union. Worldwide semiconductor growth in recent years have been largely driven by increasing demand for consumer electronics and telecom products such as mobile phones, FPD TV, notebooks, portable music players, mobile phones etc. During the global recession, sales in Asia Pacific remained flat, whereas that in America and Europe witnessed a steep decline.6-11

By 2020, the Indian share of the chip market is expected to be US$ 50 to 60 billion.
By 2020, the Indian share of the chip market is expected to be US$ 50 to 60 billion. Over the last two years, chip consumption has increased 61.44% to $8.25 billion. Right now, India adds value by way of design, accounting to a modest $2 billion. Value addition to this design comes in the form of chip manufacturing to the tune of $20 billion worth in countries like Taiwan, China and Korea, based on chip design work done in India and finished electronic goods worth US$ 60 billion plus based on these chips. India needs to have a large number of fabrication facilities, for which investments to the tune of US$ 4 – 6 billion is required for every fabrication facility. Augmentation by way of R&D investments every 18-24 months for technology updating is also needed. Compared to dismal number of chip fabrication units or semiconductor chip manufacturing foundries for large scale production, domestic manufacturing facility is required to manufacture chips to be used as audio/video/ general purpose processors, microcontroller’s, memories, etc.

It is essential to build facilities for assembly, testing, and packaging for the manufactured chips, Embedded/real-time software to run these chips, a supply chain to cater to all the critical equipment and chemicals is considered ideal. A concerted effort between government, industry and academia is required in areas of training technical human resources to run and manage fabs, study the market trends, analyzing and adopting business models, develop relationships with supplier and customer base, develop appropriate policy support mechanism and carry out cutting edge R&D. Some efforts are already in place through the Department of electronics and information technology, GOI. India would become a major player for low volume high critical technology and high volume less critical technology to meet needs of manufacturing of a large electronic product mix.

DEMAND PROJECTION 2035
Electronics, reported at US$ 1.75 trillion worth production now, is the largest and fastest growing manufacturing industry in the world. Demand for electronics in the Indian market is expected to grow from US$ 45 billion to US$ 400 billion by 2020 and US$ 3200 billion by 2035 at a growth rate of 15%. The export market is likely to move from US$ 4 billion to 80 billion by 2020. With setting up of new manufacturing facilities, export contribution of US$ 800 billion by 2035 should be aimed for. The trend of imports/exports needs to be reversed. This scenario may improve and may touch $1200 Billion by 2050. The imports are more than what we can export in electronics. This is not favourable for GDP, CAD and Nation debts. The graph shown in Plate 1 and 2 gives the projected demand-supply gap.
Among numerous great inventions made in the 20th century, electronics has played a dominant role. According to a recent survey, Electronic End Equipment has become the base of all political and economical activities and staked a share of the world’s total GDP of about USD 30,000 billion. Almost everything related to human needs, such as power generation, transportation, communication, entertainment, medical care, economic activities like stock market, financial transactions are now provided and controlled by electronics. Semiconductor, being the key component of the Electronic End Equipment, is a strategically important technology for all countries. The electronic circuit development has been accomplished through down scaling of component size brought out by the replacement of vacuum tubes with transistors 40 years ago. Circuit performances have benefited a lot from the downsizing. It is now possible to integrate millions and billions of CMOS transistors in the nano scale in a silicon chip of few centimeters square. Right now, the operation speed of the latest microprocessor has already reached
3 GHz and is expected to increase further\textsuperscript{17}, although recent trends indicate that increase of clock frequency may gradually saturate. The CMOS integrated circuits as well as their core device technologies are expected to evolve further for around a decade and their importance will taper off in future giving way to new emerging technologies to meet the needs of the present intelligent society.

PRESENT DAY STATUS OF THE SEMICONDUCTOR INDUSTRY

Semiconductor manufacturing today is a mature technology, with global revenue of US$300 billion and manufacturing facilities in over 20 countries. It is the cornerstone of global IT economy, supporting a $2 trillion market in electronic products and an estimated $6 trillion in service industries across sectors ranging from health care and transportation to banking and defence. The dominant manufacturing process used today for digital electronics is called the complementary metal oxide semiconductor (CMOS) process.

With the establishment of manufacturing-independent design rules for integrated circuits, IC designers no longer need to be co-located with the manufacturing side of the business. This decoupling led to the creation of the electronic design automation industry. Semiconductor manufacturing ecosystem today has mostly bifurcated into fabrication-less (fabless) companies, which design their products and outsource the manufacturing to a third party, and foundries, the companies that provide a non-competitive manufacturing facility for fabless companies. A few manufacturers who design and manufacture their own products in house, called as integrated device manufacturers (IDMs) also exist. Today, Japan, Taiwan and Korea have an established position in the industry, with China slowly ramping up its foundry capabilities. While U.S. companies have led the microprocessor market, Japan has historically led in memory products. In recent years, however, Korea has taken the lead in memory products, as well as the mobile devices industry. China with appropriate policy support from government is attracting foreign manufacturers to set up foundries there, with end effect of its semiconductor industry occupying 11% of global industry in 2009 as against 2% in 2000.\textsuperscript{18,19}

The industry is now reaching the basic physical limits to linear CMOS scaling. To avoid leakage current, manufacturers now scale down the device at constant voltage (approximately one volt), which has effect of exponentially increasing the power emitted when the transistor operates at high speeds. With the heat generated by a processor already exceeding that of a hot plate, further reduction is not a viable option. The continued ability to achieve full benefits of scaling is thus diminishing as manufacturers are being forced to trade-off between transistor density and performance (speed) to avoid excessive increases in power density of the chip. There is growing interest in technologies that would carry the industry past the scaling limitations. Exploring technologies to improve chip performance via increased system-level functionality, in what is called the system-on-chip concept is one of the major areas of industrial R&D. Other researchers are actively engaged in the development of new devices, new physics, new material that can function at much lower voltages and could allow continued miniaturization beyond the limits now imposed by the CMOS transistor. There is a trend to use FINFETs as the new option replacing CMOS.

TECHNOLOGY GAP ANALYSIS

India is well known for its software power. On the hardware front, the progress is rather slow with approximately 50 electronics manufacturing services (EMS) and original design manufactures operating (both indigenous and global players) in India. Further moves by international players are expected to add production in India in the coming years. Low labour cost, fast growing domestic market, excellent education system, technology parks and improvements in transit and utility infrastructure are considered favourable points for India, where as of now no operational wafer fabrication units exist. Indian presence in the semiconductor industry, a key driver to entire electronic system chain, has been limited to four government units. The establishment of a fab city in Hyderabad with 14 manufacturing units is expected to create 1.4 million jobs through 200 odd ancillary units. Many of the drivers for semicon...
industry, such as, the cost competitiveness, talent pool, IP protection, proximity to APAC countries etc. are favourable to India.

The current day electronic manufacturing requirements could be understood from the Frost and Sullivan study that indicates that of the 25 high priority electronic products, which account of 82% of overall consumption of electronics in India, the top 5 alone accounts for 60% of the consumption. These products are communication networks and switching equipment such as mobile phones (38.85%), FPD TV (7.91%), Notebooks (5.54%) and desktops (4.39%); solar cell panels, storage devices and associated devices; power electronics/supplies; LCD displays; memory and PCB. The report also suggests that 69% of the local consumption of the top 25 priority products is currently met through imports.20

The future requirements could be next generation products like smart TV with FHD and UHD resolution display and studio equipment, also with digital network alliance features, quantum computers capable of delivering extra fast performance for tasks requiring long and complex computation, machines which can recognize emotions, Industrial robots for different applications like underwater; Medical, Surveillance and intervention, Edutainment, etc. MEMS and NEMS for automotive, aerospace, medical, Defence, require the manufacturing facilities with latest technology nodes.

The next generation power electronics, which convert and control electrical power across the grid and is in a growing array of products used by industry, consumers, military and other utilities, will be using Wide Band Gap (WBG) semiconductors, which will improve the efficiency of industrial motor system, consumer electronics and data centers, conversion of renewable power etc. Some of these could be done with low end technology with low risk and low investment but has advantage of meeting a specific demand sector.

Forecasts indicate that most of today’s key semiconductor and electronic packaging technologies are not capable of meeting the needs of the industry in 2019. Technologies for the future should address these challenges with innovative solutions, to strengthen the viability of the electronics manufacturing industry. Even though further scaling of CMOS semiconductors has many difficulties, they are expected to be in the market beyond 2020 for low-end solutions. International Technology Roadmap for Semiconductors (ITRS) has made predictions relating to future scaling for 10 years up to 2018, when the physical gate length is expected to be 7 nm.16-19. Gate oxide thickness should be two orders of magnitude smaller than that of the gate length. From the present 1 - 2 nm thick oxynitride film being used in production, it is expected that the silicon dioxide equivalent thickness (EOT) will be reduced to 0.5 nm in 10 years time. MOS transistor with 1.5 nm or the recent 0.8 nm may face challenges during the construction of large-scale integrated circuits with such thin gate insulators. It is believed that the CMOS device downsizing is approaching the physical limit. The ultimate limit of the scaling is the distance of atoms in silicon crystals (0.3 nm), when the gate leakage will reach unmanageable limits.

New Technological Options: Performance enhancement can be achieved and further downscaling may be proceeded with the introduction of new technologies and materials at least for another 10 years and furthermore with that of three-dimensional structures. New materials and processes for sub-100 nm device manufacturing such as elevated source/drain, plasma doping with flash or laser annealing, Nisi silicide, strained Si channel for mobility enhancement, silicon on insulator (SOI), three-dimensional...
structure high dielectric constant (high-k) gate insulator, metal gate, and low dielectric constant (low-k) interlayer insulator for interconnects have been explored recently. These measures are already on schedule for future technology nodes. FinFET is another contender. However, some unexpected device parameter degradations were reported with the new materials. High-k gate insulator is an example. Fortunately, scaling is not the only solution for performance improvement. The improved circuit structures and system architectures such as parallel processing architecture and system-on-chip (SoC), optimized interconnect can also make the integrated circuits to perform better. It is expected that the overall performance of our electronic system could be enhanced further at least down to the generation of 20 or 10 nm gate lengths as consequences of both the improved device technology and the new system structures.

ROADMAP FOR THE SEMICONDUCTOR INDUSTRY
Technology planning and R&D in the semiconductor industry is a large-scale, long-term, and multi billion dollar operations, which has to be largely collaborative. To keep electronics industry vibrant and growing, technology planning may be as follows - near term technology (More Moore), medium term technology trends (More than Moore or System on Chip) and long term technology (beyond CMOS/beyond Moore).

It should be emphasized that these technology developments are not sequential but occur in parallel with advances in one feeding into another area. Each of these trajectories will require substantial changes in design, architectures, system integration models, and process technologies.

NEAR-TERM TECHNOLOGY TRENDS (“MORE MOORE”) This category includes modifications in design and materials in the current manufacturing processes to compensate for the limitations in linear scaling and extend the benefits of the CMOS process to the maximum possible extent.16,17

Device and Materials Continued Scaling: Continued scaling of transistor dimensions results in extreme heat dissipation at the limits of high performance. Manufacturers now seek to improve chip performance using a combination of continued dimensional scaling, to the extent feasible and cost effectiveness. Towards this, “Equivalent scaling,” that is, changes in materials, design, and process that combine to give a performance improvement equivalent to scaling down the chip (e.g., introducing new materials such as high-K dielectrics in place of the traditional silicon dioxide insulator) and using three-dimensional transistors such as the FinFET and the tri-gate transistor is becoming increasingly relevant. Design-equivalent scaling, such as, use of multi-core architecture, general purpose graphical processor units (GPGPUs) and different modes of low power design to drive improved performance is yet another option. Though only marginal improvements are gained, all these methods utilize the parallel-instruction capability of multi-core processors to achieve speed-ups.

In the areas of memory and storage, research has focused on unifying hard-disk memory and chip-based memory into a single unifying non-volatile memory. Technologies such as the phase-change memory, ferroelectric RAM (FeRAM), and magnetoresistive random access memory (MRAM) are under development as potential replacements for the universal flash memory.21

Materials: Several materials are being researched and characterized for their potential insertion into CMOS devices (replacing the channel) to improve performance, as well as form the basis of new “beyond CMOS devices.” The materials attracting the most attention are graphene, carbon nanotubes, and compound semiconductor nanowires. As the silicon-based CMOS process has been a technological juggernaut for the past four decades, there is enormous resistance to the integration of new and old materials—including compound semiconductor materials and germanium as they are not compatible with the existing manufacturing processes.17

Integration: During integration of various circuit blocks on same chip there is a problem of interconnect delays that limit
the performance of any IC. New strategies of interconnect such as CNT interconnects and three-dimensional integration of circuits are being explored. In three-dimensional integration of circuits two or more layers of active electronic components are vertically integrated into a single circuit using through-silicon vias (TSVs), which will dramatically reduce interconnect lengths and thus transmission delays. Three-dimensional integration for stacking memory and logic components provides a higher memory density at lower power for mobile applications. This concept of moving system integration to the third dimension has been called “the largest shift of the semiconductor industry ever, one that will dwarf the PC and even consumer electronics eras.”

Transmission: Silicon photonics are being developed to enable integration of optical transmission systems onto the chip, overcoming the constraints of today’s copper interconnects. This would result in faster and more energy-efficient chips than are possible using conventional technologies. Silicon photonics circuits have recently been demonstrated and are a few years away from commercial production. In future circuit optical interconnects will be using 3-D, nanophotonic solutions.

Manufacturing Process: Lithographic patterning is critical for defining lateral dimensions on the chip and translating design into product. There is currently a pressing need for next-generation lithography (NGL) technologies for nanoscale printing, and leading equipment manufacturers are in a close race to bring future lithography techniques such as extreme ultraviolet (EUV) lithography to market. EUV Lithography has its own limitation and is not a cost effective technology and new emerging technologies are plasmonic lithography, which can overcome the limitations of EUV lithography.

As emerging devices scale down to nanometer and very low-end nanometer levels, robust and efficient methods for atomically precise placement and solutions for intelligent fault tolerance are becoming essential. At simulation level, new paradigms are emerging for quantum mechanics based modeling and characterization of process compatible designs. On the factory-floor, globally distributed production systems need to become increasingly scalable, flexible, and extendable. Improving all these characteristics for improving process control is essential. Further, as manufacturing systems are increasingly automated and subject to remote control, information security and cyber-security become essential. Future low-end nano technology solutions may need self-assembly at the large-scale production.

MEDIUM-TERM TECHNOLOGY TRENDS (“MORE-THAN-MOORE” OR “SYSTEM-ON-CHIP”)
This methodology involves incorporating analog devices (such as sensors, actuators, RF devices, audio and video power circuits and passive components), which are typically integrated at the system board level, to be placed directly onto the chip (also called system-on-chip, or SoC). A compact system with heterogeneous functionality will
drive the proliferation of integrated circuits for improving communications systems, bioelectronics, and transportation.

The United States leads in these technologies, but Korea and Taiwan are highly competitive.

Device and Materials: “More-than-Moore” or “System-on-Chip” is the idea of integrating heterogeneous components onto the silicon platform to increase the functionality of the chip itself.1

As against the present method, wherein processor is connected to other system components such as power source, external memory, RF chips, sensors, etc. on the motherboard, using wires made of copper, in an SoC paradigm, these system components would migrate directly onto the silicon platform. At first the system components would be vertically separated and as manufacturing processes evolve they would be eventually stacked vertically. This would optimize performance at the system level and extract much larger improvements in system performance than linear scaling alone is able to do. The first SoC manufactured would likely integrate processor, memory, and communication chips; eventually, MEMS, sensors, and biologics would also be integrated. Advances in three-dimensional integrated circuits and silicon photonics would feed into SoC technology. There will be an increasing emphasis on field-programmable gate arrays (FPGAs) and a shift away from application-specific integrated circuits (ASICs) as chip technology becomes more for general purpose. This would also open up possibilities for mass customization of chips, produced inexpensively and programmed at the software level such as for embedded system designs.18

Manufacturing Process: SoC system will combine digital and non-digital (sensing, audio/video sub-systems, power supplies, communication, and fluidics) elements on the same platform; thus, suitable materials integration of such sub-systems on the same foundry floor must be found for the new applications23, 24. These will have to be integrated into the CMOS manufacturing technology. While leading manufacturers are in a competitive race to ramp up heterogeneous-integration methodologies for the silicon platform, incorporating new functionality will need cross-disciplinary work and new learning for the industry. More automation and standardization will be needed for the new processes introduced. Manufacturers of SoC and three-dimensional integrated products will initially be more vertically integrated, which will cause big shifts in the highly modular and globally dispersed ecosystem of the semiconductor manufacturing industry. Further, processor-packaging technologies (flip-chip bonding) would be replaced with three-dimensional packaging technology.

Three-dimensional packaging saves space by stacking separate chips in a single package, making it more economical for low-cost manufacturing but issues such as cross-talk, removal of heat amongst various layers of the circuits and optimum layout planning is required.
LONG-TERM TECHNOLOGY TRENDS ("BEYOND CMOS/ BEYOND MOORE")
This trajectory includes research on emerging devices and materials, focused on a "new switch," which will initially supplement the functioning of the current CMOS and eventually supplants it. These devices and memories are anticipated to use new state variables (such as electron spin, magnetic spin, molecular state, etc.), which allow functional scaling substantially beyond that attainable by “scaled CMOS.” Examples include carbon-based nano electronics, spin-based devices, ferromagnetic logic devices, atomic switches, and nano electromechanical-system (NEMS) switches.16-19 etc.

Device and materials: The limits of CMOS scaling have also infused an urgency into the vision of discovering new, highly scalable concepts for information processing and memory functions to enable orders-of-magnitude higher miniaturization than that is possible using silicon CMOS devices. These concepts could be based on a new “token” (such as electron spin or molecular resistance) to represent electric charge as a means to represent information. Quantum Information and computing systems will be round the corner.

The change to a new information-processing technology will likely be accomplished in two phases: in the first, the potential new technologies would have to be integrated with existing CMOS processes to extend chip functionality beyond what would be possible with CMOS alone, such as a hybrid technology. The second phase would see the evolution to completely new, multifunctional and scalable technology platforms.16 This second phase is at the basic stages of research, and it will likely continue past the 2035 time frame.

The new devices being explored for “Beyond CMOS” technology may perform processor or memory functions or in some cases, a combination of both functions in a universal device. They should ideally show significant advantages over ultimate scaled devices in power consumption, frequencies of operation, and density. They should also be capable of integrating with the CMOS process, to allow insertion into heterogeneous or hybrid systems, thereby enabling a smooth transition to a new scaling path. These goals are driving research in graphene, carbon nanotubes and nanowires, among other materials. While many ideas are being pursued, a representative sample (based on demonstrated feasibility)21 would include a) field-effect transistor (FET) devices that can operate at lower voltages, such as band-to-band tunneling FETs, b) nanomagnetics and spintronics, which exploits the spin properties of electrons (both individual and collective oscillations), c) resistance-based memory devices or conductance devices (resistive random access memory, or ReRAM), d) single electron transistors and d) molecular devices.

It would be interesting to note that recent advances based on magnetic spin properties include products like MRAM, which could be a key component in defence systems that require radiation-hardened devices and non-volatile memory. Metal-based spintronics are likely to reach commercialization first, using a phenomenon called spin-torque transfer for storage and applications (called STT-RAM). Semiconductor-based spin devices are still very much in the research stage. The resistive memories will be very dense and easy to stack. Non-volatile memory integrated with logic is also being explored. The spin electron transistors are switching devices that use tunnelling mechanisms to transport single electrons from source to drain. While these devices hold the potential of ultra-low-power electronics, significant obstacles remain in the noise margins, control of meta-stable states before SETs can be used in large-scale circuits. Molecular devices are based on molecular switches that switch reversibly between two or more positions. The use of molecular switches as programmable diodes is the core technology underlying projected applications. Logic, memory, and interconnect functions have been demonstrated using molecular assemblies, but integration onto a circuit is still a long-haul research goal.

Manufacturing Processes: Bottom-up manufacturing processes such as directed self-assembly of molecules (currently shortlisted on the international roadmap for further investigation) will start being
incorporated into the existing CMOS platform for building heterogeneous devices and eventually play a larger part in improving process control at lower costs.\textsuperscript{18} Currently, self-assembled structures of diblock copolymers are being used as an alternative to photoresists for sub-10 nm features in design patterns. However, the scale and scope of investment in the current manufacturing methods is such that a full shift to bottom-up manufacturing is predicted to be a decade away.

Incorporating new materials onto the silicon platform in ways that their functionality can be fully exploited Beyond CMOS is yet another challenge. This trajectory includes research on emerging devices and materials, focused on a “new switch,” which will initially supplement the functioning of the current CMOS and eventually supplant it. These devices and memories are anticipated to use new state variables (such as electron spin, magnetic spin, molecular state, etc.), which allow functional scaling substantially beyond that attainable by “scaled CMOS.” Examples include carbon-based nanoelectronics, spin-based devices, ferromagnetic logic, atomic switches, and nanoelectromechanical-system (NEMS) switches.

DOMINANT TRENDs IN TECHNOLOGY AND MANUFACTURING
The next two decades would witness technology trends such as a) low-power and low-energy systems, which will be needed as more devices (especially those with integrated sensors, SoC, MEMS etc.) have to integrate seamlessly with the environment, b) increasing wireless capability and connectivity, particularly as cloud computing needs escalate, c) convergence of computation, storage, sensing, and communication functionality on the chip by integrating heterogeneous materials and components, d) increasing use of nanoscale processes in device fabrication; slow but eventual transition from top-down to bottom-up manufacturing will be necessary, e) storage and management of increasing volumes of data while addressing integrity, safety, security, and privacy concerns, f) Influx of biological devices based design, architecture, and concepts, ultimately aiming for massively parallel, fault-tolerant neuro-morphic systems. Cumulatively, these trends would enable advances in powerful and intelligent electronic products as well as enhanced modes of human-computer interaction.\textsuperscript{25}

Printed electronics is another promising area to play a dominant role in the next generation electronic products manufacturing, with market for printed, flexible and organic electronics growing to USD 76.79 billion by 2023. Printed electronics may enable new markets for large-area, flexible or low-cost disposable devices. Using printing to fabricate electronic devices promises lower manufacturing costs because of the additive, non-vacuum nature of the technology and the advantage of roll-to-roll or large-area processes.

4.0 RECOMMENDATIONS

- Setting up of manufacturing units for very low cost (low risk) and ultra high performance (high risk) electronic products (controllers and micro controllers) through FDI wherever possible or with real national effort in mission mode.
- Creating ITI’s offering training in high-tech ICT products and centres of excellence in electronics and other emerging domains.
- Policies to support flexibility for industry to adapt to new product chains as future directions of Electronics are always in flux and are dynamically changing from time to time.
- The established SMEs should be able to meet the ultra high precision requirements of current day electronic manufacturing and also cope up with new challenges.
Some major recommendations for setting up fabs for meeting domestic needs are:

- N-3 or more through FDI or large scale expansion of existing fabs, which could be mandated to produce devices for low end technology nodes and meet the power electronics type demands.
- Establishing ITI type training institutes that have high end skills, which the leading industries of India can utilize for taking up manufacturing of low end and high end device and systems.
- Mandating educational institutions, R&D organizations and other Govt. agencies to take up problem solving for emerging domains of technologies, along side training of manpower to handle such problems when employed by the industry.
- Technology up-gradation should be the prime goal of industry who want to be major players and
- Major investments and handling of high end technology should be made by the industry, in tune with practices followed in US, Japan and Europe.

It is expected that the adoption of these recommendations could have advantages such as employing cost effective technologies, equipment, infrastructure etc. to produce products with lower global market share but is able to support large local industries. The industries that would benefit from these low-end fabs are those relating to renewable energy, solar panels, silicon and hybrids, inverters, UPSs, automotive electronics, Micro-controllers, analog, mixed-signal, FPGAs, MEMS and audio equipment. Another major segment that would benefit from these lower end fabs are the health care industries comprising of sensors, mobile/wireless diagnostics and treatment equipment, industrial level electronics and automation and FMCGs. If more fabs are needed over and above mentioned existing Indian Industries they should only be set up under private sector only and Govt. of India’s involvement should be minimum except provide licenses. This has to take into account the past mistakes.

Once the manufacturing ecosystem is set up, and is a successful as a business model (viz. market, customers, revenues, growth, etc.) for Indian conditions – it will yield a platform (and confidence) to go for high technology manufacturing.
REFERENCES


GRAND CHALLENGES

1. Guaranteeing requisite material and energy for the growing manufacturing industry needs at globally competitive costs

2. Taking Indian manufacturing to global best in terms of material, energy and water consumption leading to reduced environmental footprint

3. Ensuring skilled manpower, appropriate level of automation, precision and productive fabrication equipment, design capabilities, globally acceptable testing facilities and standards

4. Transforming Indian food processing to meet quantity and quality requirements through zero waste methods

5. Making India a globally competitive producer of textiles and apparels through adoption of superior technologies

6. Ensuring sustainable manufacturing technologies to turn all available raw material into value added consumer desired leather products

7. Building indigenous cost effective nano structuring, coating, replication and metrological capabilities

8. Providing state of art fabs and infrastructure to promote large scale ICT and electronic appliances manufacture in India
• Vibrant ecosystem needs to be in place to incubate the new technologies into industries, leading to high value jobs for a large number of young Indians by 2035.

• Reinventing the current manufacturing practices by ushering in new technologies and employing green manufacturing processes.

• ICT and adaptronics needs to be exploited to produce a structural change for sustainable manufacturing systems in the country.

• Target to achieve world class level in terms of quality, supply and cost in materials (both raw and processed), energy, water, supply chain, automation (including software), skilled and productive manpower.

• New technologies for supporting the driving factors for competitive manufacturing like reduction in investment and space, high flexibility and modularity, low life cycle cost, production systems, high strength, high performance, multi functional and bio-inspired materials coupled with lean manufacturing concepts.

• Cohesive linking of academia, government and industry is required. Linking manufacturing hubs to research institutes and universities with a mandate to create technologies to ensure global competitiveness and develop productive and skilled human resources is essential.

• Efficient and seamless integration of manufacturing processes, micro/nano technologies, mechatronics, process control, production planning, resources and materials management, simulation technologies, efficient logistics and short supply chains, knowledge modelling and management, efficient exploitation of information and networking technologies needs to be ensured.

• Research on key enabling technologies to generate new production scenario and futuristic automation systems is essential.

• Widespread implementation of distributed manufacturing using 3-D printing technologies and enlarging the technological envelope of manufacturing in traditionally strong fields like textiles and leather, chemicals, pharmaceuticals and high precision fabrication forms the core of the technology vision for manufacturing.

• India should strive to be a global leader in composites for general engineering, automotive and aerospace industries, micro/ nano manufacturing with focus on health care and energy harvesting and create infrastructure for a global standard ICT to support manufacturing and develop food processing to meet local needs and needs of ever growing Indian Diaspora.

• The immediate need in the next ten years is to train a breed of manufacturing engineers who can turn research output into marketable products and services.

• At present, manufacturing sector lacks capacity building in machine building/ equipment fabrication, which requires immediate attention.

• Our educational institutions should become nurseries of innovation than from being mere degree-awarding factories, and challenge our students to think and work innovatively during their education. Universities and higher educational institutions should be rated based on their contributions/output on innovations.

• A conducive environment for mentoring innovations and encouraging technology start-ups in this sector, is the need of the hour.
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TIFAC, India’s think tank has recently brought out the Technology Vision 2035 document, which was unveiled by the Honorable Prime Minister of India, Shri. Narendra Modi on 3rd January, 2016. This document outlines the aspirations of Indians in 2035, the different prerogatives they would be assured of and also the technologies that would enable them to be achieved.

To turn the vision into reality, TIFAC is supplementing the Vision document with comprehensive technology roadmaps on 12 sectors it deals with. The technology roadmaps would provide insights on future technology trends, R&D directives, pointers for research, business opportunities, anticipated challenges, policy imperatives pertaining to each sector. Manufacturing is one of the sectors, for which technology roadmap has been evolved.